SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

Preaeration and Air Flocculation—Roe

Chemistry of Cyanide Wastes—Milne

Synthetic Rubber Wastes Disposal—Dougan and Bell

Flushing of Tidal Estuaries—Ketchum

FEBRUARY, 1951—VOL. 23, No. 2

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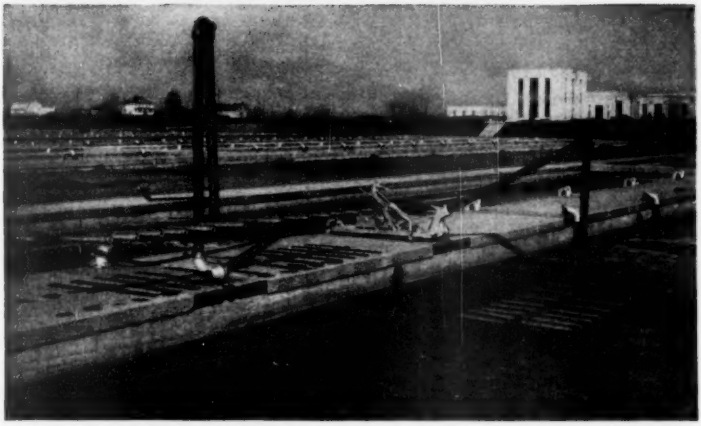

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SEWAGE AND INDUSTRIAL WASTES

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A monthly Journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of such works.

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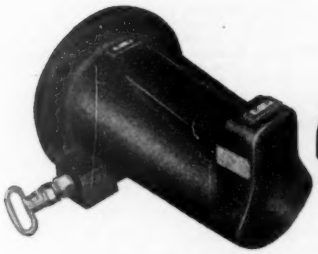

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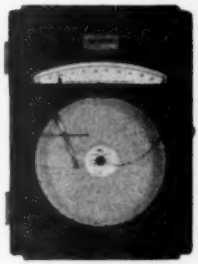

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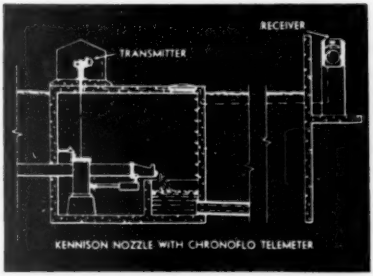

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HOW TO MEASURE TRADE WASTES ACCURATELY

In accordance with anti-pollution laws recently enacted by numerous states, most industries now face the task of purifying their plant wastes before discharging them into adjacent streams and rivers.

This purification process usually requires special plant construction, and invariably the necessity exists of obtaining flow data, whether this be the simple indication of flow rate or a more permanent method of recording and totalizing the flow through the plant. With purification processes of this kind, measuring equipment usually is located at the point of discharge of partially filled pipe or in open channels, where low heads or pressures exist and where measurement is either difficult or impossible when using standard forms of measuring instruments.

The Simplex type S Parabolic flume, either alone or in conjunction with a Simplex type HF water float operated meter, is the ready answer to this measuring problem. Compact in design, with no pockets or grooves to catch sediment or solids, and capable of operating under low flow conditions, the unit measures over long ranges, from maximum to 5% of maximum capacity.

Available in standard pipe sizes of 6 inches to 36 inches diameter inclusive, the flume can be attached to even larger sizes by means of eccentric reducers.

Write for Bulletin 210, to the
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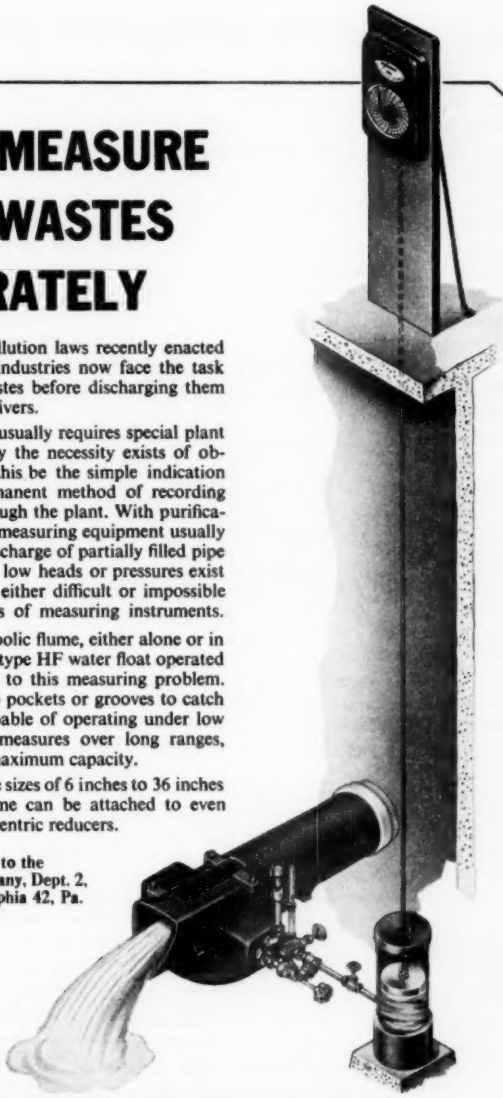

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Association	*Place*	*Time*
Texas Water and Sewage Works Association	Texas A. & M., College Station, Tex.	Mar. 11–15, 1951
New Jersey Sewage and Industrial Wastes Association	Haddon Hall, Atlantic City, N. J.	Mar. 14–16, 1951
Arizona Sewage and Water Works Association	El Tovar Hotel, Grand Canyon, Ariz.	Mar. 28–30, 1951
Louisiana Conference on Water Supply and Sewerage	Louisiana State University, Baton Rouge, La.	Mar. 28–30, 1951
Virginia Industrial Wastes and Sewage Works Association	Hotel Chamberlin, Old Point Comfort, Va.	Apr. 5–6, 1951
Arkansas Water and Sewage Conference	Hot Springs, Ark.	Apr. 9–11, 1951
Kansas Sewage Works Association	Lamer Hotel, Hays, Kans.	Apr. 11–13, 1951
Montana Sewage Works Association	Hotel Placer, Helena, Mont.	Apr. 19, 1951
California Sewage Works Association	Hotel Californian, Fresno, Calif.	Apr. 25–28, 1951
Pacific Northwest Sewage Works Association	Hotel Vancouver, Vancouver, B. C.	May 15–16, 1951
Michigan Sewage and Industrial Wastes Association	Hotel Pantlind, Grand Rapids, Mich.	June 4–6, 1951
New York Sewage and Industrial Wastes Association and New England Sewage Works Association	Springfield, Mass.	June 7–8, 1951
Alabama Water and Sewage Association	University of Ala., Tuscaloosa, Ala.	June 15, 1951
Ohio Sewage and Industrial Wastes Treatment Conference	Neil House, Columbus, Ohio.	June 20–21, 1951
Pennsylvania Sewage and Industrial Wastes Association	State College, Pa.	Aug. 22–24, 1951
Iowa Sewage Works Association	Hotel Tall Corn, Marshalltown, Iowa	Sept. 11–13, 1951
Kentucky–Tennessee Industrial Wastes and Sewage Works Association	Kentucky Hotel, Louisville, Ky.	Sept. 17–19, 1951
Missouri Water and Sewerage Conference	St. Joseph, Mo.	Sept. 30–Oct. 2, 1951

Federation of Sewage and Industrial Wastes Associations
Municipal Auditorium, St. Paul, Minn.
October 8–11, 1951

New England Sewage Works Association	Sheraton-Biltmore Hotel Providence, R. I.	Nov. 6–7, 1951
North Carolina Sewage and Industrial Wastes Association	Robert E. Lee Hotel, Winston-Salem, N. C.	Nov. 12–14, 1951

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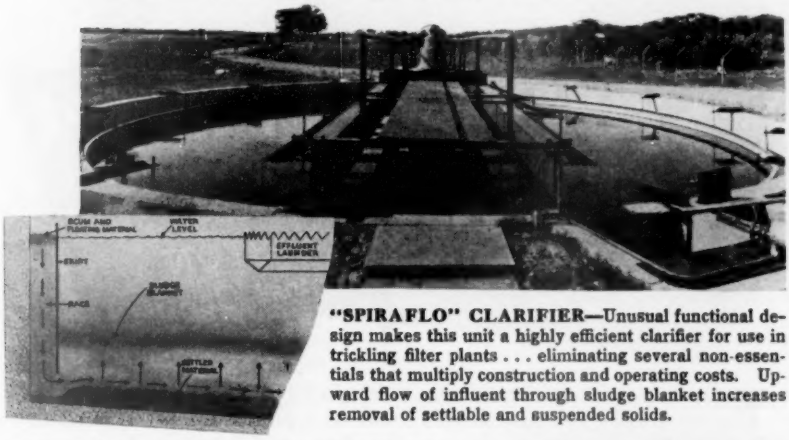
YEOMANS "SPIRAFLO" CLARIFIER and "AERO-FILTER"

SINGLY . . . OR IN COMBINATION

. . . especially in the treatment of strong industrial wastes

Low construction cost . . . low operating cost . . . high purifying efficiency: these are the characteristics of the Yeomans "Spiraflo" Clarifier and the "Aero-Filter System," whether used separately or in combination.



"SPIRAFLO" CLARIFIER—Unusual functional design makes this unit a highly efficient clarifier for use in trickling filter plants . . . eliminating several non-essentials that multiply construction and operating costs. Upward flow of influent through sludge blanket increases removal of settlable and suspended solids.

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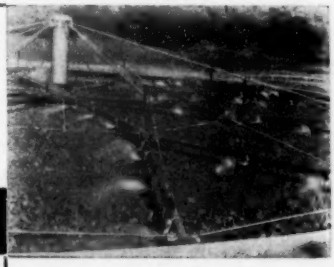

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1411 N. Dayton St., Chicago 22, Ill.

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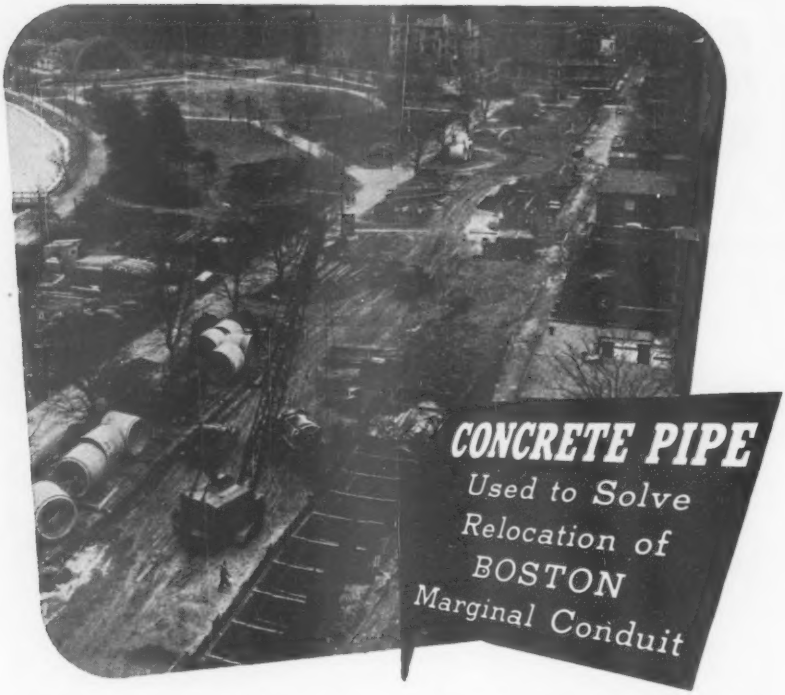
FIT ANY REQUIREMENTS—Overall plant efficiency is always higher when the two units are used in combination; however, plants using either type of equipment or the combination can be designed to fit any needs for treating domestic and industrial wastes.

IMPORTANT INFORMATION—Facts as to remarkable records established by Yeomans units will be helpful in your project planning. Bulletins containing performance data, field engineering data and construction cost estimates are available on request—use the coupon.



TO make way for a vehicular tunnel on the new four-lane James J. Storrow Memorial Embankment Expressway along the Charles River in the Back Bay section of Boston it was necessary to relocate an 8-ft. diameter marginal conduit.

Because of its many qualities, reinforced concrete pipe was chosen for the new sewer. In all, 2040 ft. of 96-in. straight pipe and 225 ft. of 96-in. radius pipe were used, manufactured in 8-ft. lengths (ASTM specification C76-41, Table 1).

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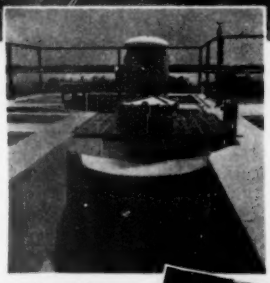
A complete laboratory and staff of competent engineers are available for making recommendations and reports to the consulting engineer or his client. It is, of course, intended that this service shall cooperate with the work of your engineers. When considering your next sewage treatment plant, or the modernization of an existing one, call in your nearest INFILCO Field Engineer, or write our executive offices in Tucson.



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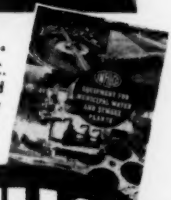
Bulletin No. 60-C. It illustrates and describes many items of Infilco Equipment.



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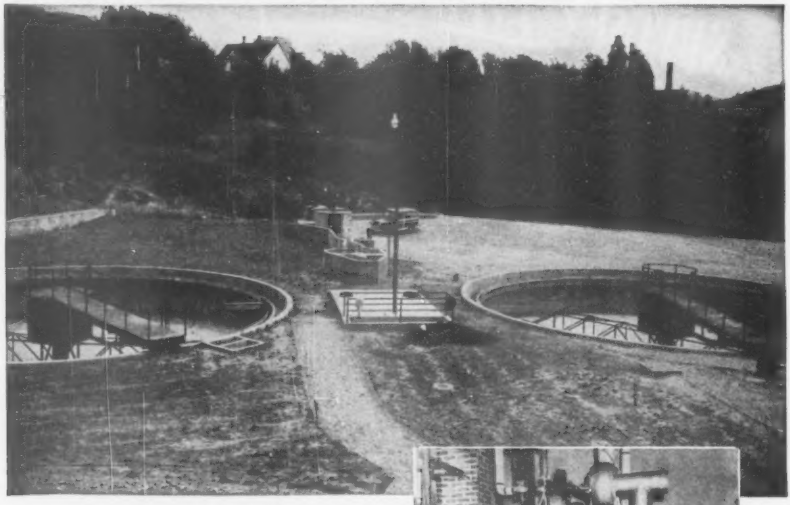

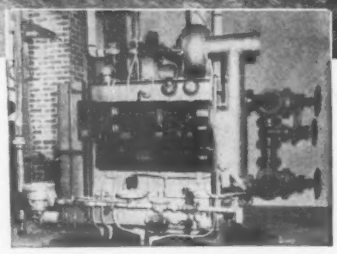

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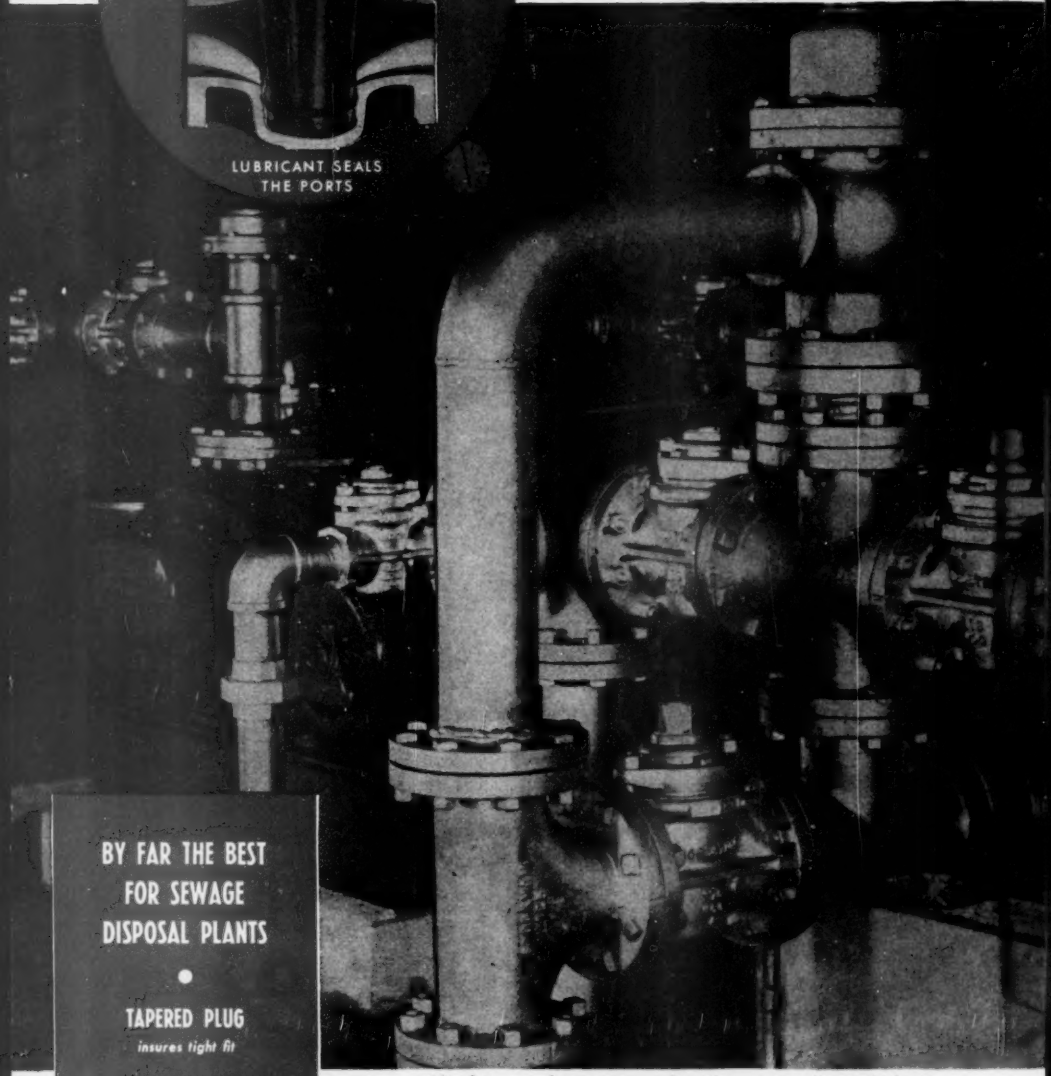

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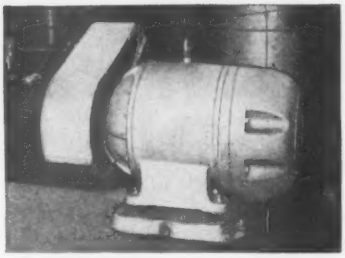

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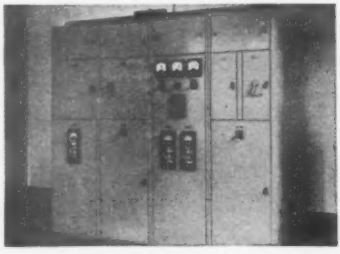

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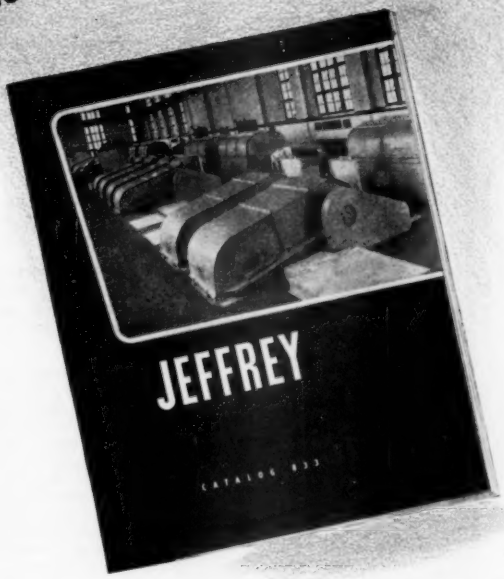

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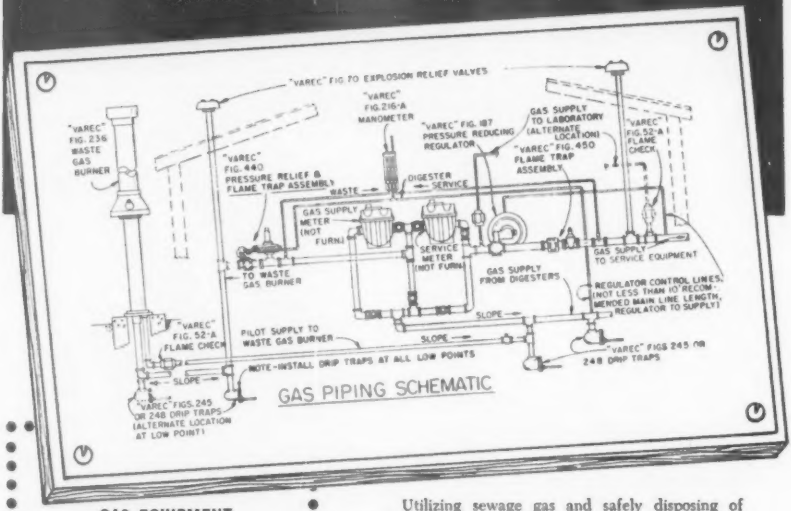
"VAREC" FIG. 236 WASTE GAS BURNER
"VAREC" FIG. TO EXPLOSION RELIEF VALVES
"VAREC" FIG. 216-A MANOMETER
"VAREC" FIG. 187 PRESSURE REDUCING REGULATOR
GAS SUPPLY TO LABORATORY (ALTERNATE LOCATION)
"VAREC" FIG. 450 FLAME TRAP ASSEMBLY
"VAREC" FIG. 52-A FLAME CHECK
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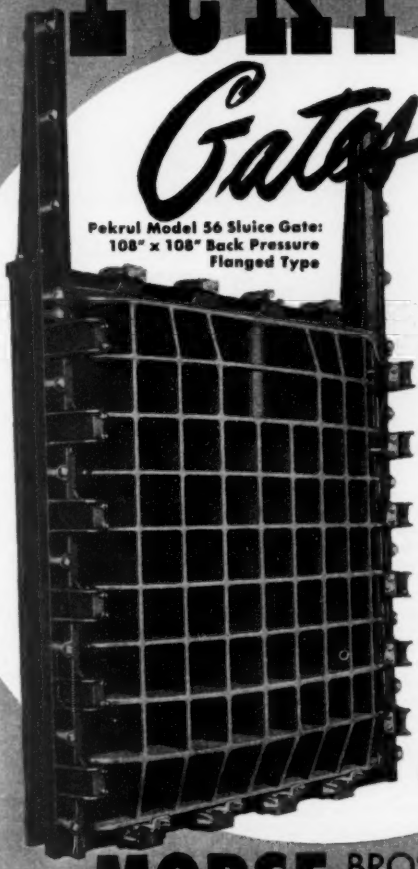

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 23 **FEBRUARY, 1951** **Number 2**

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Sewage Works

PREAERATION AND AIR FLOCCULATION *

By Frank C. Roe

Development Engineer, The Carborundum Company, Perth Amboy, N. J.

A careful study and review of the subject of preaeration and air flocculation reveals that probably no other single step of modern sewage treatment practice has received so little analysis and performance reporting for such versatile, extensive, and beneficial use. Sewage works engineers have recognized the advantages of the combined process for many years, but its widespread adoption apparently has been based largely on general knowledge and observation, rather than as a result of specific analysis or correlation of operating results.

It was the void of positive information concerning preaeration and flocculation, plus full recognition of the exceptional value, that prompted preparation of this paper (12). The analysis presented is based primarily on a survey of past and present experiences at operating plants in the United States, rather than on original scientific work, but it does cover an extensive area of application.

Lists of preaeration plants in each state were secured early in 1950 through the cooperation of Department of Health engineers. There were 91 plants listed in 18 of the 33 states that reported. Design and operating data questionnaires were then sent to each of the 91 plants, and replies were received from 38—a 42 per cent return. Data were also obtained from 13 additional known plants not listed, so that a claim of reasonably good coverage seems justified. It is true, of course, that there are possibly 50 per cent more preaeration units in operation which are unknown, or may be located in the states that did not furnish information.

As might have been expected from the poor record of published reports on preaeration, many of the questionnaire replies contained no comprehensive operating data. Sufficient results and reliable information were received, however, to establish a pattern of practice that will at least serve as a guide to the analysis and design of preaeration units for existing or new plants.

What is Preaeration?

Preaeration is defined by the "Glossary—Water and Sewage Control Engineering" (1) as "a preparatory treatment of sewage comprising aeration to remove gases, add oxygen, or promote flotation of grease, and aid coagulation." A brief review of the subject by this author (2), back in 1933, revealed that such benefits were then recognized, and that a number of plants were accomplishing one or more of the objectives as now formally stated.

The variable period or intensity of preaeration as practiced in the United States coincides with the broadness of the definition. Often there is a reason for a small degree of treatment in one place and extensive aeration in another location because of variable conditions or objectives, but just as often the period of preaeration has no definite basis. Such differences have led to some misunderstanding, or to questions

* Presented at 23rd Annual Meeting, Federation of Sewage and Industrial Wastes Associations; Washington, D. C.; October 9–12, 1950.

concerning the value of the process. One of the objectives of this analysis, therefore, is to clarify the various functions of preaeration and point up the apparent requirements for each function.

Early use of preaeration of raw sewage normally was for the purpose of odor control and/or prevention of septicity. In general, short aeration periods ranging from 15 min. down to less than 1 min. were used. The additional benefits of grease separation and flocculation of solids became evident as the period of aeration was increased. The latter benefits, in fact, now are considered the major objectives of the process. An additional benefit (or "by-product"), where the preaeration tank is adjacent to settling units, has proved to be uniform distribution of flow and solids to settling tank inlets.

Within the last few years air diffusion has been used successfully for grit separation, as distinguished from the standard functions of preaeration. Normally this is accomplished with but a few minutes of air diffusion, so that the only automatic but important "dividend" is odor control and favorable conditioning of sewage for subsequent treatment.

It will be noted that the definition of preaeration, as stated, includes aiding coagulation of solids, which agrees with the usual conception of the process. It is not clear where such coagulation or flocculation ceases and complete biological flocculation and oxidation as a somewhat distinct process continues. Further discussion in the following section attempts to clarify this point.

Theory of Preaeration

The several variables of normal domestic sewage and the combined functions of preaeration establish such a complex relation in treatment that any single hypothesis of what occurs seems impossible. The complexity increases if industrial wastes are involved. It, therefore, seems reasonable to simply enumerate the chemical and physical changes that occur and offer an explanation.

Raw sewage often arrives at a plant devoid of oxygen and containing quantities of grease and entrained H_2S and/or CO_2, each factor presenting a treatment problem. The diffusion of air into such sewage, immediately following arrival, effects these changes:

1. Reverses the potential of the sewage from negative to positive, thereby promptly stopping the reduction of certain solids and oxygen-containing compounds that otherwise require an undue amount of oxidation in subsequent stages of treatment. Undoubtedly, this achieves the state of "treatability" referred to by Kappe (3) and Walker (4) in earlier discussions of this subject.

2. Enhances the coagulation and dewatering of emulsified grease particles, so that a greater percentage will float and be removed from the surface of settling compartments.

3. Sweeps out entrained H_2S if pH is below 7.0, thereby eliminating objectionable odors from the remainder of the plant and the vicinity, protecting lead-base paint, etc.

4. Sweeps out entrained CO_2 and thus increases alkalinity, so that sewage generally is more treatable and will not have a detrimental effect on concrete structures.

Continued preaeration beyond that required for the above functions provides additional oxygen for the respiratory group of sewage organisms, which accomplish coagulation and agglomeration of solids. This secondary, and possibly more important, phase of preaeration comprises both mechanical and biological flocculation of organic solids. It was thoroughly reviewed and well explained by Heukelekian (5) in 1941.

Extensive work at Ridgewood, N. J., by Hood and Eckenfelder (6) shows rather conclusively that plain aeration

can be continued for hours and days, if necessary, with progressively improved results to the point of 100 per cent reduction of B.O.D. The long periods of aeration required obviously make such practice impractical. It is infinitely more economical and equally effective to return aerobic sludge or liquor containing the thoroughly developed respiratory organisms to the incoming sewage, as in the activated sludge process. The work reported by Setter (7), Mann (8), and Gunson (9) seems to corroborate this theory.

As the definition and usual conception of preaeration includes flocculation of solids, it is suggested that the process should be considered simply to encompass all plain aeration of raw sewage. The varying point where it becomes more economical to return active sludge or liquor to the influent in order to produce a given B.O.D. reduction will become established for each condition. Such a change establishes a different process, which should take another name.

Practice and Results

Odor Control and Prevention of Septicity

All statements contained in returned questionnaires and letters were definite, without exception, in the opinion that the objective of odor control and prevention of septicity is satisfactorily and readily accomplished by preaeration. Because observation is immeasurable and dependent on man's sense of smell and sight, as well as on individual standards, there is variable enthusiasm concerning benefits, however real and valuable they may be.

An exception is at Ridgewood, N. J., where the condition of sewage before and after preaeration is measured by oxidation-reduction potential to indicate the actual benefit. A few other comparisons of over-all results with and without preaeration confirm the theory of rendering sewage more "treatable." This usually can be translated into secondary treatment cost savings.

Several of the plants reported utilization of preaeration for odor control and "sweetening" of sewage only. In most of these cases, the periods of aeration were only a few minutes and no other benefits were noted, except even distribution of solids to settling tank inlets.

Grease Separation

Of the 51 plants from which reports were received, 18 indicated intentional use of preaeration for grease separation, but only 6 gave figures. Removal of fats ranged from 40 to 65 per cent. One report gave an average quantity figure from domestic sewage of 0.443 cu. ft. per m.g. Another report gave 7.0 cu. ft. per m.g., indicating unusually high concentration in raw sewage.

Among the other reporting plants which use substantial preaeration, efficient grease separation is unquestionably accomplished. Practically all settling units are equipped with grease skimming facilities.

A review of the literature covering this particular phase of preaeration included one comprehensive study of U. S. Army camp plants by Eliassen and Schulhoff (10). It concludes that the process was negative at such plants in achieving improved results over settling alone. The extremely important factor of aeration time was not correlated in that analysis, however, and the report indicates that a short period of 10 min. generally was practiced. Gehm (11) states that improved grease separation as a part of high solids removal will result from increased aeration time. This is confirmed by others, and is strongly supported by the analysis of solids removal that follows.

Grit Separation

Five of the 51 plants reporting utilize preaeration for grit separation,

although only three were originally constructed for that objective. Data were only supplied in one report. On a yearly basis, this showed removal of 0.921 cu. ft. per m.g.

Although this is reported as a new or incidental function of preaeration when units are properly equipped, it promises to have increased use. For maximum benefit from air input, such units will probably be designed to simultaneously accomplish some of the standard objectives.

Removal of Suspended Solids

The most complete and significant results were reported for the important and valuable function of suspended solids removal. Many data were inconsistent, but the pattern that developed, as illustrated by Figure 1, is fairly well supported. Some analysts of the plotted data would, perhaps, draw different curves among the points, and more data might indicate some changes of slope. It is believed, however, that there would be general agreement with the interesting relations as shown.

These results substantiate a logical opinion, expressed many times, that the higher the solids content of raw sewage, the greater the efficiency of air flocculation and sedimentation. Increased aeration, of course, improves coagulation of solids and increases efficiency of removal, as is strongly indicated.

It was expected that the factor of settling period following preaeration would be confusing in this analysis because of possible inability to correlate it with reported results. This did not develop, however, as 45 per cent of the total number of plants reported retention periods in settling tanks of approximately 120 min. and the average from all plants that submitted data was 122 min. Those plants with shorter settling periods generally reported values that fell below the curves, and those with unusually long periods showed results better than indicated by the curves. Consequently, the results expressed by Figure 1 are premised on what appears to be a basic sedimentation period of 2 hr. following preaeration.

Reduction of Oxygen Demand

If reduction of 5-day B.O.D. were referred to as an objective or special benefit of preaeration, there undoubt-

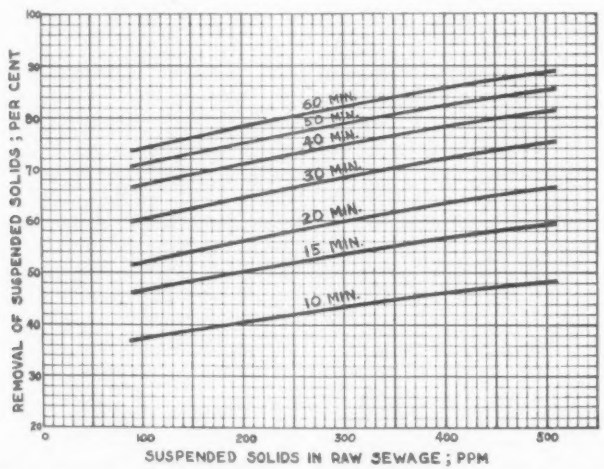

FIGURE 1.—Removal of suspended solids by preaeration and 120-min. sedimentation.

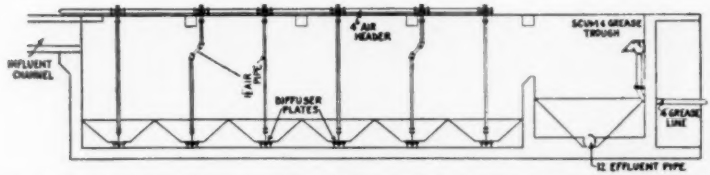

FIGURE 2.—Longitudinal section of ridge and furrow design of preaeration tank with skimming compartment.

edly would be a basis for controversy. The discussions and analysis for this paper, however, lead to the conclusion that preaeration simply prepares and improves the material for oxidation, and that the reduction of B.O.D. is only incidental to the removal of suspended solids. In contrast, a few early discussers suggest accomplishments in this category by preaeration; a total of 26 plants out of the 51 supplying data for this analysis reported 5-day B.O.D. reductions.

Although 10 plants reported B.O.D. reductions in excess of 50 per cent, data by settling alone were not included; therefore, no evaluation could be made as to the benefit derived from aeration. Plotting of B.O.D. reduction data, as furnished, developed no correlation whatever, as the raw sewage from every plant varies in suspended and dissolved solids characteristics. Both poor and good removals were reported on similar strength sewage, even when aeration periods were longer for the plants reporting poorest results.

Another reason for inability to correlate B.O.D. reduction results is that the important factor of sewage temperature is not reported generally. The previously referred to work at Ridgewood, N. J., by Hood and Eckenfelder (6), showed that a 10° C. drop will decrease effectiveness of preaeration materially in reduction of B.O.D. It also showed that longer aeration and/or the addition of active sludge to the colder influent will maintain desired results.

Methods of Preaeration

Some mechanical aerators have been used for preaeration within the past 20 years, but only one report was received for this analysis covering such a unit. The remaining 50 that reported employ air diffusion and all but four use porous ceramic plates or tubes for diffuser media.

Porous diffuser media have proved more efficient for the dispersion of air than perforated pipe, for example, because much smaller bubbles are re-

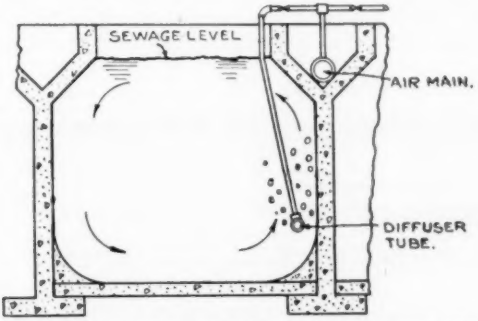

FIGURE 3.—Cross-section of typical spiral flow preaeration tank with diffuser tubes.

FIGURE 4.—Spiral flow "wide band" aeration tank with swing diffusers (Chicago Pump Co.).

leased. Experience has shown that maintenance cost of porous ceramic diffusers is equally low, as long as the air supply is clean and is maintained with very few interruptions. Freedom from corrosion is a favorable maintenance factor for porous ceramic media.

From an efficiency viewpoint, there is no distinction between diffuser plates and diffuser tubes. For preaeration, especially where grit separation is included, suspended diffuser tubes generally have proved more practical than fixed horizontal diffuser plates. This is because they are elevated above any accumulation of inorganic solids on the tank bottom. Such tubes have a further advantage, in that it is unnecessary to dewater and take a unit out of operation for servicing.

Aeration Tank Design and Equipment

Early designs involved the installation of longitudinal rows of diffuser plates in channels or long tanks. Several "ridge and furrow" designs with transverse rows of diffuser plates (Figure 2) also were used. A few of these are still in service.

When the "spiral flow" design was developed for activated sludge treatment, the same design was utilized for preaeration units. Most of these were equipped with a longitudinal row of suspended diffuser tubes (Figure 3). An improvement in the spiral flow tank

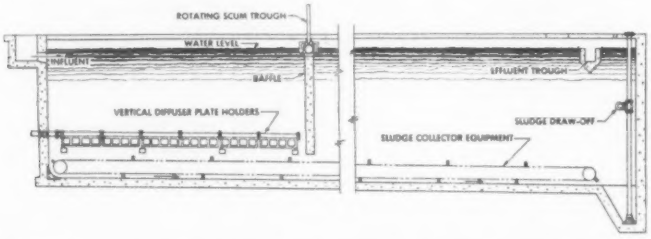

FIGURE 5.—Combination preaeration and sedimentation unit (Pacific Flush Tank Co.).

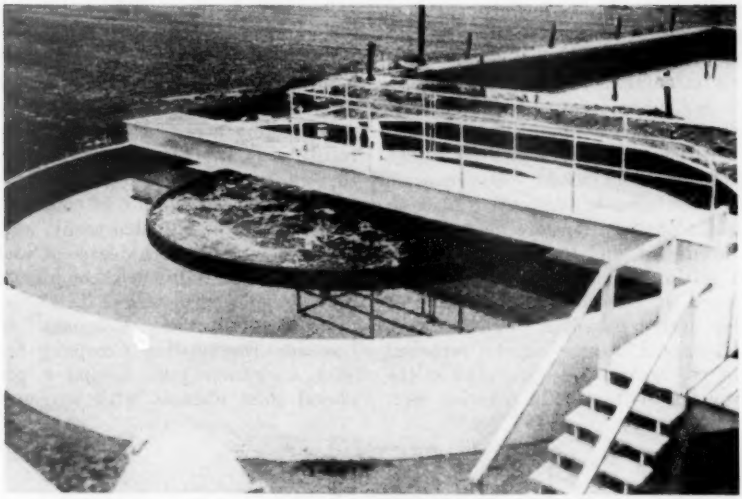

FIGURE 6.—Operation of "Oxidator" at Hemet, Calif. (Process Engineers Inc.).

design is provided by "wide band" diffusion of air and the type of equipment for swinging tubes out of tanks (Figure 4) manufactured by Chicago Pump Company.

The rising tide of favorable opinion concerning the benefits of preaeration is evidenced by some of the more recent tank design and equipment developments. The first of these (Figure 5) was by Pacific Flush Tank Company. It offers the unique combination of aeration unit and settling compartment in a single straight-line tank. The aeration compartment is baffled and equipped with vertical diffuser plates along both sidewalls. Sludge collector flights traverse the full length in the direction of flow. Units of this design are now operating in at least four places, and some of the most favorable data for this analysis were received therefrom.

Process Engineers Inc., have perfected the unusual and interesting design shown by Figures 6 and 7. It is

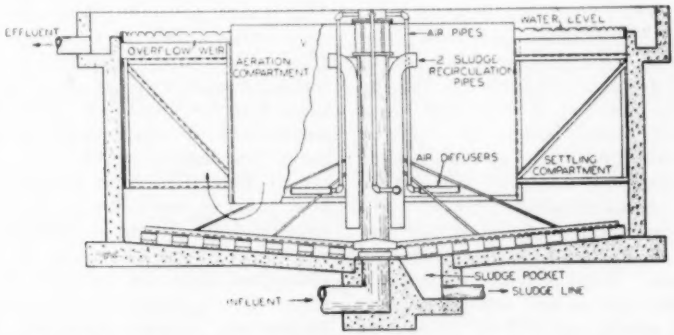

FIGURE 7.—Cross-section of "Oxidator" unit (Process Engineers Inc.).

now used extensively in California and elsewhere with outstanding results. The principle involves a central inlet to a circular aeration compartment. Diffuser tubes are suspended radially from the center column like the spokes of a wheel, and revolve with the sludge collecting mechanism. Oxygenation and flocculation of solids takes place in this compartment, where general flow is downward, and thence to the annular settling compartment. Flow is upward in the latter, with effluent going over a peripheral weir.

If desired, sludge can be returned from the central collecting zone at the bottom to the top of the aeration compartment. Excess sludge is withdrawn from a slightly off-center sump.

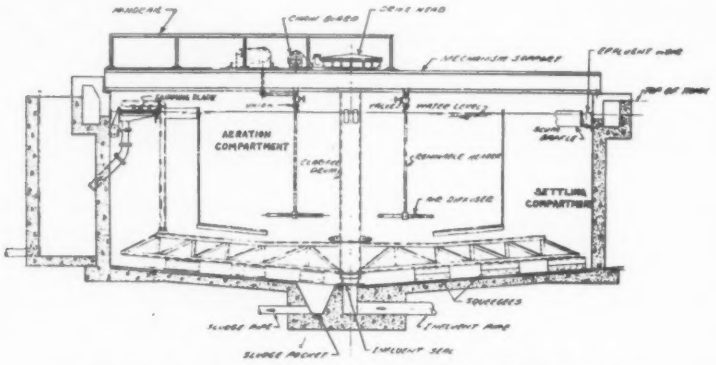

FIGURE 8.—Cross-section of aerator-clarifier unit (Dorrco.).

The Dorr Company has developed a circular combination aerator-clarifier unit with fixed diffuser tubes in the central aeration compartment (Figure 8). The aeration compartment has a partially closed bottom to minimize short circuiting. The annular settling compartment is equipped with an efficient grease-skimming device. The initial installation of this design was made at Ypsilanti, Mich., some two years ago. It has provided remarkably good flocculation and removal of suspended solids, with D.O. in the effluent averaging 3.2 p.p.m.

The outstanding feature of the three combination aeration-settling tank designs described is the flexibility for handling an extremely wide strength range of sewage or industrial waste, and meeting a similar wide range of result requirements. It is apparent that the size of each portion of tank units can be varied and, of course, air diffusion can be adjusted easily, as required. Where a high degree of treatment is required, such combination units are placed in series.

Yeomans Brothers Company and Lakeside Engineering Company both offer a circular tank having a peripheral inlet channel with suspended diffuser tubes to aerate the tangential flow of incoming sewage (Figure 9). This design, called the "Spiraflo" because of the spirally vertical path taken from bottom inlet to top outlet of the settling compartment, is not to be confused with the spiral flow course taken horizontally in conventional aeration tanks from inlet to outlet.

Grit separation tank designs have been based on spiral flow aeration with suspended diffuser tubes. Hoppers are strategically located to receive grit that settles out when the optimum rate of turnover (normally 1 ft. per sec.) is maintained. Further reference to or illustration of this function is omitted

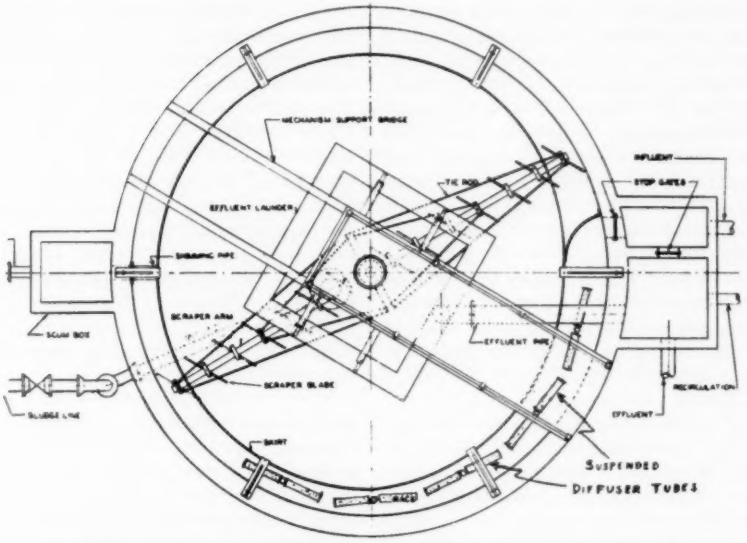

FIGURE 9.—Plan of typical "Spiraflo" clarifier (Yeomans Brothers Co. and Lakeside Engineering Co.).

because it does not come within the usual conception or definition of preaeration and, as of now, is somewhat incidental.

It frequently is possible to add preaeration to an existing plant by installing diffusers in a channel leading to the preliminary settling tank or tanks. Or such a channel may be the only kind of structure that can be built on available space. Normally it is necessary to maintain an influent channel in use at all times, whereas special preaeration units can be taken out of operation, if need be, for servicing. The most practical and widely installed aeration equipment for channels that must be maintained in use is the suspended type of diffuser assembly (Figure 10) offered by Link-Belt Company. A somewhat similar design, with orifice control to each tube, is manufactured by Chicago Pump Company.

Air and Diffuser Requirements

The variables that affect the quantity of air required to satisfactorily accomplish the several functions of preaeration are essentially physical in nature. The size and shape of tank, type of air diffuser, and diffuser submergence are the principal factors.

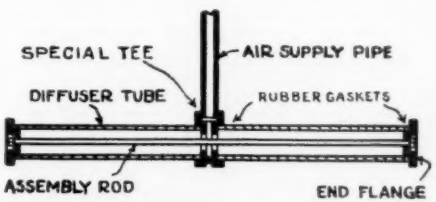

FIGURE 10.—Typical suspended diffuser tube assembly (Link-Belt Co.).

Considering all functions of preaeration as outlined herein, the primary use of the air is mechanical, even though the oxygen supplied by the bubbles is also important to development of best results. Thus, the amount of air essential to properly agitate and maintain all solids in suspension throughout the aeration unit is the fundamental requirement. This will vary from 1.0 to 4.0 cu. ft. per lineal foot of tank, depending on the variable factors stated above, tank cross-section in particular. Small, shallow channels require relatively little air, as compared with deeper and wider tanks.

The quantities given above are adequate for good coagulation and flotation of grease solids. They also provide ample oxygen for arresting a negative potential or reducing condition of raw sewage, and for preliminary activity of the respiratory organisms that are so essential to flocculation of solids and subsequent oxidation treatment. If entrained gas is difficult to remove, the rate of diffusion will be on the high side of the range stated.

When the data on air consumption were taken from all returned questionnaire forms and plotted to develop Figure 11, there was not a very clear-cut pattern through the short period range. Some of these variations were due to fixed air blower capacities, which could be high or low for any given condition. The major variation, of course, is due to considerable variation in dimensions of physical structure. The requirements shown by Figure 11 are based on average values for tank units of liberal, but not extreme, proportions. This is a straight-line requirement, based on increasing the total length of preaeration units for increased retention period.

Normally, the number and size (or area) of air diffusers is established by dividing the total estimated air requirement by the optimum rate of air diffusion per unit. This rule is not inflexible because both the distribution (location) of diffuser units and the rate of diffusion per lineal foot of any given tank must be considered first, to insure proper agitation. For preaeration, however, there is not a great deal of difference in efficiency between air diffusion rates of about 3.0 and 6.0 c.f.m. per sq.ft. of diffuser area. Thus, if air blower capacity can be varied

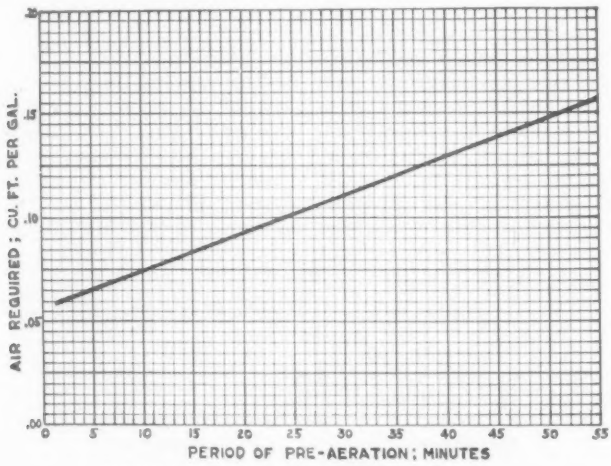

FIGURE 11.—Air requirements for preaeration.

somewhat to meet variable conditions and the proposed diffuser layout results in an average diffusion rate within the range stated, satisfactory operation is quite certain to be attained.

Conclusions

It is apparent, when reviewing this analysis point by point, that the combined functions of preaeration and the variables that exist in the treatment of any sewage make conclusions somewhat more general than specific. Taking those functions in order, the following summation seems to be well substantiated:

1. Preaeration establishes a positive (oxidation) potential and prevents septicity of domestic sewage in relatively short periods of 5 to 15 min.
2. Entrained H_2S and CO_2 gases are removed readily in equally short periods of time, effecting odor control and otherwise improving conditions for subsequent treatment.
3. Efficiency of grease separation generally is increased to 60 per cent or better by use of a minimum of 20 min. preaeration, and preferably 30 min.
4. Mechanical and biological flocculation of solids commences with short periods of aeration and continues steadily, with improved results, as the aeration period is increased. The degree of treatment desired (with sedimentation), or the total cost before the return of biologically active sludge to influent becomes a more economical process, will establish the required plain aeration period.

An evaluation of the foregoing leads to the further strong conclusion that preaeration will improve the treatment results generally at practically any sewage plant. Tank units (or channels) and equipment are simple and easily adapted to proposed or existing construction.

The final observation that is well supported by this analysis is the repetition of a claim often made by this author and others: that preaeration accomplishes more in actual performance or analytical results per total dollar expended than any other step of primary or secondary treatment. Beyond this is the intangible benefit of conditioning sewage so that it is more treatable, thereby increasing the success and/or decreasing the cost of secondary oxidation processes.

Acknowledgments

The author wishes to express his sincere appreciation to the many people who contributed pertinent information, operating data, and valuable advice for the preparation of this paper. The list is too extensive to include herein, but comprises the following groups: State Department of Health engineers, plant operators and superintendents, equipment manufacturers, and consulting sanitary engineers and chemists. Without the help of these people, this analysis of an important subject would not have been possible.

Particular appreciation is expressed to W. H. Wisely and F. W. Gilcreas for their suggestion that this study be undertaken and for their advice on procedures.

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DISCUSSION

By Uhl T. Mann

Superintendent, Ley Creek Sewage Treatment Plant, Syracuse, N. Y.

This discussion attempts to review the information presented by Mr. Roe. It is quite apparent that Mr. Roe's task was made difficult because of the many variables—namely, sizes and shapes of tanks, methods of diffusing air, location of diffusers, and quantities of air. Also, in most instances, plants supplying operating data were not equipped physically to treat sewage flows with and without preaeration at the same time.

Mr. Roe has covered the subject matter of his paper quite thoroughly. The paper defines and explains the theory of preaeration, describes practices and results, methods, tank designs, equipment, and air requirements.

In the section entitled "Theory of Preaeration," Mr. Roe states, "Continued preaeration beyond that required for the above functions provides additional oxygen for the respiratory group of sewage organisms, which accomplish coagulation and agglomeration of solids." This is referred to as a secondary phase of preaeration and rather implied to be flocculation. This statement brings forward the first point of this discussion. Are not preaeration and air flocculation two different processes, with each having a definite purpose as a treatment process?

A survey of sewage works literature reveals that normally preaeration does not provide aerobic conditions. This is not intended to mean that certain organisms are not taking up oxygen, but that there is never any surplus of oxygen. The benefits of preaeration are brought about by the influences of physical forces during a period of from 1 to 15 minutes.

With the practice of air flocculation, an attempt is usually made to establish aerobic conditions in order to promote biological action. In the latter process, time may vary from 30 min. to 2 hr. or more.

Mr. Roe has made reference to a paper by Heukelekian (1), in which flocculation is defined as: "Coalescence of finely divided suspended matter in sewage in the absence of biologically active slime, primarily under the influence of physical forces. The term is applied to short period mechanical or air diffusion processes where biological action is at a minimum."

In the studies at the Ley Creek plant in Syracuse with plain aeration over a period of six months, it was found that when aerobic conditions were maintained a slime developed on the walls of the tanks without any return of biologically active sludge. It might be pointed out that it is difficult to separate the influence of physical forces from the biological forces as stated by Heukelekian (1) in the same

article. However, this process was short-time aeration without the addition of biologically active sludge.

There have been several instances of full-plant operation with plain aeration, which actually constitutes air flocculation, and in most cases the results were far better than would normally be expected from the effect of physical forces alone.

Mr. Roe reports that the long periods of plain aeration required to approach 100 per cent reduction of B.O.D. make such practice impractical. Also, that it is infinitely more economical and equally effective to return aerobic sludge or liquor containing the thoroughly developed respiratory organisms to the incoming sewage, as in the activated sludge process. He also states that the work by Setter (2) and Mann (3) corroborate this theory. It appears that Mr. Roe has presented his reference to plain aeration in a misleading fashion by the quotation of "100 per cent reduction of B.O.D."

The papers by Setter (2) and Mann (3) point out that plain aeration will afford a positive degree of treatment between the limits of primary and activated sludge treatment. Also, that plain aeration can be advantageously applied for pretreatment where conventional secondary treatment units are seriously overloaded or where they are subjected to abrupt shocks of strong industrial wastes. The results of these studies indicate that shock loads may be tapered off and that effective reduction in loads on following secondary treatment units may be expected; also that economies in air requirements and sludge handling may be accomplished.

Secondary treatment processes should be regarded as methods for treating the dissolved organic material and the colloidal solids, which cannot be treated and removed by pretreatment methods. It is far more economical to pretreat sewage to reduce loadings on final treatment processes, which are the most costly to operate.

A comparison of Mr. Roe's curve for 30-min. preaeration followed by 2-hr. settling with a curve developed from laboratory data by Gehm (4) on eastern sewages, which had been flocculated for 30 min. and settled for 1 hr., shows a surprising similarity. Comparable results with 1-hr. settling as shown on Gehm's (4) curve may be explained by improved conditions for settling in a laboratory study, which might not be possible on a plant scale. It is interesting to note the similarity of laboratory study data to data supplied from many plants on full-scale plant operation.

Under "Methods of Preaeration" it is noted that porous ceramic plates or tubes were in use in the majority of plants reporting. In the past few years there have been several new types of aeration devices placed on the market. Most prominent are the so-called "Precision" tube, which is a corrugated metal cylinder wound with Saran twisted cord, the jet aerator, and the impringement aerator.

Under the heading "Tank Design and Equipment" Mr. Roe points out that several manufacturers now offer combination tanks for aeration and settling which depart radically from normal sewage treatment units. Several of these combination units have been in operation for a number of years and have proven to be quite exceptional treatment units.

There is no doubt that Mr. Roe is well qualified to exploit the field of air requirements. It is quite evident that most older preaeration units are using far more air than shown on Mr. Roe's curve of air requirements.

It is evident that there is a decided trend toward pretreatment of sewage with air in new plants, as well as the incorporation of the process in many existing plants. Preaeration offers several advantages for all types of treatment. From personal experience with

an activated sludge plant it is believed that the most important single benefit is that of smoothing out or tapering off shock loads.

This discusser is still perplexed regarding the first point brought out herein; namely, are not preaeration and air flocculation two different processes with each having a definite purpose as a treatment process?

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DISCUSSION

By Frank C. Roe

During the extensive discussion of this interesting subject at the 23rd Annual Meeting in Washington, D. C., on October 9, 1950, some important points were raised. The author would like to repeat these and to add his comments.

It was suggested that suspended solids removal with 2-hr. sedimentation and no preaeration might be at least as efficient as indicated by Figure 1, at least for the 10-min. and 15-min. preaeration periods. Some reports justify that supposition, but it is believed that settling tanks and equipment of modern design would be a prerequisite. It must be remembered, also, that the data supporting Figure 1 were from a wide variety of plants, many of them quite old.

The basic thought to bear in mind here was covered in the first section of the paper: that the usual functions of short-period preaeration have been for odor control, prevention of septicity, and grease separation. Although good removal of suspended solids has been noted in many places with short preaeration periods, it is obvious that more efficient flocculation will develop as aeration periods of, say, 30 min. and longer, are used.

This, in turn, brings up the point raised by Mann in his comments: that the author has discussed "preaeration" primarily, and not "flocculation." It is the author's observation that flocculation of solids and the conditions that promote the greatest efficiency thereof commence with the shortest of aeration periods. Although the function of such short periods may not be to flocculate solids and improve removal, the process has started and it would be difficult to say where one function is accomplished and another reaches a higher level.

Summarizing, it is not believed that preaeration and air flocculation are separate processes, but are distinctly related. The term "air flocculation" could be used alone if the sole function is improving of suspended solids removal, but that suggests a change in the established broad definition of "preaeration" stated at the outset. Such a change likely would be confusing to the profession at this stage.

STUDIES ON THE EFFECT OF RADIOACTIVE PHOSPHORUS ON THE BIOCHEMICAL OXIDATION OF SEWAGE *

By Werner N. Grune and Rolf Eliassen [1]

Research Associate and Assistant Project Director, New York University, New York, N. Y., and Professor of Sanitary Engineering, Massachusetts Institute of Technology, Cambridge, Mass., respectively

The research work reported herein is part of a broad program to determine the effect of sewage containing radioactive isotopes on plumbing and sewer systems, sewage treatment processes, and streams. As reported by Gorman and Wolman (1)(2) and Western (3), radioisotopes in increasingly greater quantities are being discharged into sewers from hospitals, research laboratories, institutions, and industrial establishments. To establish reasonable tolerance levels for the amounts of radioactivity that may safely be carried in sewers, sewage treatment plants of various types, and streams, it is necessary to investigate the effect of various forms of radioactivity on the microbiological organisms associated with sewage and streams.

The studies discussed herein were concerned with the effect of one of the radioisotopes presently encountered in radioactive wastes, radiophosphorus (P^{32}), on the biochemical oxidation of sewage, as measured by the B.O.D. test. The specific objectives of this research work included the following:

1. The effect on the aerobic stabilization rate constant, k.
2. The effect on the 5-day B.O.D. value, the conventional index used in sewage treatment plants.
3. The effect on the ultimate first-stage, or carbonaceous, B.O.D. value, L.

Radioactive phosphorus (P^{32}) was chosen for the initial studies because it is more easily handled than radioiodine (I^{131}) and is a known constituent of certain radioactive wastes. Radiophosphorus has a half-life of 14.3 days, emits a pure beta radiation of 1.74 million electron volts (Mev.), and decays to stable S^{32}. It was received from Oak Ridge in the form of the orthophosphate of phosphoric acid, with 7,000 to 10,000 times as much carrier phosphate being included to reduce adsorption losses.

Counting

In the case of radiophosphorus (P^{32}), accurate measurements were made of its activity present in the sewage being tested. The radioactive measurements had to be accomplished both qualitatively and quantitatively. Only in the light of such data, exhibiting the state of the activity with respect to any time and the amount of decay that has transpired, could an interpretation be applied to any apparent effects on the reaction velocity constant, k, and the ultimate oxygen demand, L. Counting was also necessary to check on the accuracy of the radioactive sewage dilutions under study.

The method of counting employed at this laboratory was "wet counting." In contrast to the usual evaporation of

* Presented at 23rd Annual Meeting, Federation of Sewage and Industrial Wastes Associations; Washington, D. C.; October 9–12, 1950.

[1] Formerly Professor of Sanitary Engineering and Project Director, College of Engineering, New York University, New York, N. Y.

liquid samples on metal planchets before counting the activity of the solid residue, the "wet" method saved considerable time and equipment (4).

Measuring apparatus, consisting of scalers, Geiger-Mueller counting tubes, and other auxiliary equipment for the detection and determination of radioactivity, had to be procured and standardized to overcome the randomness of radioactive emissions (see Figure 1). The most general, yet versatile and flexible type of radiation equipment, is the Geiger-Mueller tube and scaler. Nuclear counters to a considerable degree are still in the experimental stage; an operator must become thoroughly familiar with their operation and peculiarities in order to achieve reliable results. An understanding of the randomness and the statistical phenomena as applied to counting (5) is very necessary. It is most important to standardize the instrument initially with known standards, such as Radium D and E standard sources supplied by the National Bureau of Standards. Absolute units of activity can be obtained at a later time by direct conversion as long as conditions have remained constant.

Safety of Personnel

In order to safeguard all project personnel from inhalation and ingestion of radioactive materials, the activity of suspended radioisotope in the air was continuously determined or monitored by collecting dust samples. The maximum beta dust count ever found was 1.6×10^{-7} microcurie per liter, with the usual level of about 10^{-8} microcurie per liter.

National Bureau of Standards Handbook No. 42 (6) states that the permissible contamination level, as recommended by the National Committee on Radiation Protection, is 10^{-6} microcuries per liter in air for beta- and gamma-emitting materials. This is approximately 1/200 to 1/2,000 the values given earlier by K. Z. Morgan (7) or H. M. Parker (8), which were 2.1×10^{-4} or 1.8×10^{-3} microcuries per liter, respectively. This is pointed out to illustrate the trend for safer tolerance levels, which can be maintained.

The results of air monitoring at this

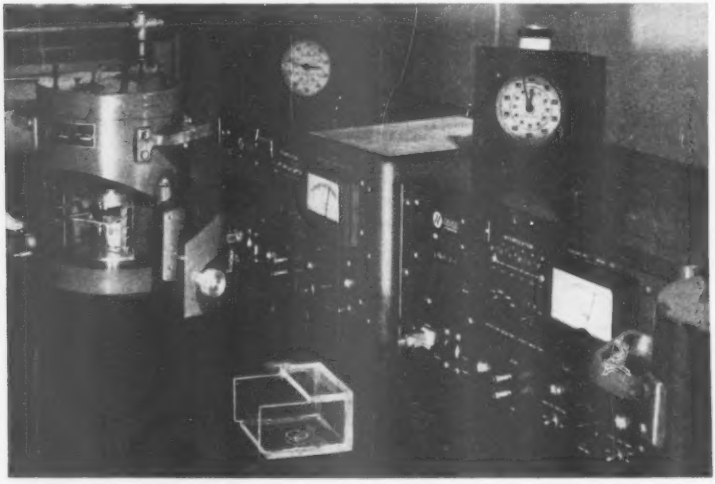

FIGURE 1.—Geiger-Mueller end-window tube scalers for radioactive counting.

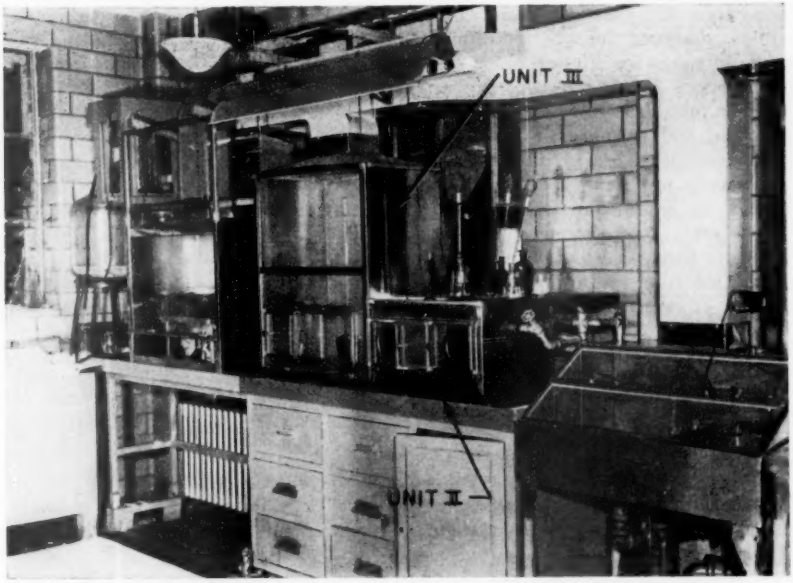

FIGURE 2.—Main section of "hot" laboratory, showing Units II and III. Unit for nitrite-nitrate evaporation at far left.

laboratory have shown that the greatest activity of the air samples was below the allowable tolerance value by a factor of 100 to 1,000 when radiophosphorus (P^{32}) was in use.

Two portable beta-gamma survey meters (9), calibrated to read from 0.01 to 20 milliroentgens per hour, were in constant use to measure localized contaminated (or radioactive) areas throughout the laboratory. Ten milliroentgens per hour is considered a high intensity of radiation; personnel must avoid working in an area contaminated to this level for any length of time. The weekly tolerance level set by the U. S. Atomic Energy Commission is now 300 milliroentgens per person per week, or 50 milliroentgens per person per day.

Design of Radioactivity Laboratory

In the course of developing the laboratory for these studies, principles foreign to the sanitary engineering field were acquired and utilized. Wherever the traditional methods of operating a sanitary engineering laboratory did not coincide with the principles of health physics, the latter always governed to provide the necessary safety for all personnel concerned (10). The shielding of radiations emitted by radiophosphorus (P^{32}) was generally handled by the use of Lucite or Plexiglass (1.74-Mev. beta rays are stopped by 6.8 mm. of Lucite, 8.1 mm. of water or tissue, or 7 m. of air) (11)(12).

The "hot" laboratory contained principally working benches, with specially designed handling equipment and stainless steel working hoods of the semi-dry box or "Berkeley" style, and a large exhaust hood for high-intensity manipulations. All the hoods were connected to a forced-air exhaust duct system.

The special features of the radiological laboratory included these specially built hoods, gloves, decontamina-

tion area for glassware, and many others, designed for the handling of radioisotopes (see Figure 2).

All hoods had to be properly ventilated to provide an air flow of between 100 and 150 ft. per min., and were provided with a drain pipe inside to carry away any waste solutions. Altogether, six hoods were installed.

The main hood served as the high-intensity hood, in which all shipments from Oak Ridge were opened and all initial dilutions made. The second hood (Figure 3, Unit I) was used to fill B.O.D. bottles. As soon as the B.O.D. bottles were filled with either radioactive dilution water or radioactive sewage, a shower spray inside the unit washed all bottles simultaneously. The radioisotope was added by means of a lead-shielded separatory funnel on a pulley system (see Figure 4). The funnel was filled with the required amount of isotope at bench level, raised, and then emptied into an 18-l. carboy containing dilution water or sewage. A permanent siphon from the carboy passed through the top of this hooded unit and bottles were filled by gravity to prevent any change in the D.O. content.

The third hood arrangement covered a large, double, stainless steel sink (see Figure 2). As laboratory glassware was constantly washed, this sink was built with a completely enclosing cover resulting in a prevailing negative pressure. In this way, radioactive splashing hazards were minimized.

The fourth and fifth hoods (see Figure 2, Units II and III) were attached to each other and exhausted simultaneously. They served the purpose of carrying out the Winkler analysis for

FIGURE 3.—Unit I of "hot" laboratory, used for filling B.O.D. bottles and rinsing them afterwards.

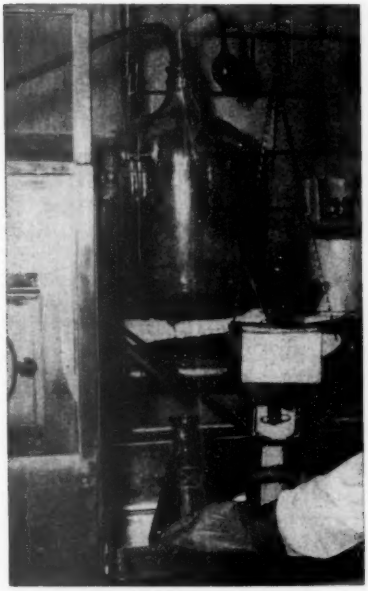

FIGURE 4.—Lead-enclosed separatory funnel filled with concentrated isotope mixture to be raised by pulley system and emptied into 18-l. carboy.

dissolved oxygen under radioactive conditions. Unit II was used to add the three B.O.D. reagents by means of Caulifield pipettors and to subsequently shake the B.O.D. bottles; the third, was used to titrate the bottles with standard thiosulfate under fully shielded conditions.

For the purpose of "Winklerizing" B.O.D. bottles, many types of mechanical and automatic devices were tried, to eliminate hand shaking of bottles. Mechanical stirrers and magnetic mixers were explored, but were found unsuitable to duplicate the natural shaking action of the wrist. For this reason the "Berkeley" type box with permanently fastened gauntlet-type gloves was adopted to perform these tasks inside the unit.

The sixth and final hood was used for evaporation of water and sewage samples in preparation for nitrate analyses. It housed a water bath and had the usual provisions for decontamination and drainage (see Figure 2).

All the units were built of 18-gage stainless steel. Constant flushing with water diluted any radioactive waste materials to levels below present tentative tolerance levels for disposal. All water connections and faucets were foot-pedal activated wherever the possibility existed that a glove-covered hand could bring contamination. All drains were connected to a common trap.

All pipetting, practiced daily for counting purposes as well as dosing radioactive sewage, was done by remote control with two biological syringes.

The design of this laboratory was based on the necessity for using rather high levels of radioactivity for quantitative observations of the direct effects of these levels on the B.O.D. of sewage. Many sanitary engineering laboratories may become engaged in studies involving tracer techniques at much lower concentrations of radioactivity. Consequently, the elaborate precautions heretofore mentioned for protection of personnel will not be needed. Consultation with health physicists would be desirable to determine the degree of protection called for by the particular level and types of radioactivity employed.

Method of Sampling, Handling, and Preparation of Dilutions

After considerable preliminary work to achieve control over tangible variables, among which were the day and time of successive sampling, a standardized procedure for the sampling of sewage was adopted. Each sample of sewage was collected weekly at 9:00 A.M. on Wednesdays (13)(14), from a sewer manhole opposite the laboratory. The sewage was filtered through non-absorbent cotton to remove large suspended solids prior to its addition to dilution water for B.O.D. tests.

The method used in preparing dilu-

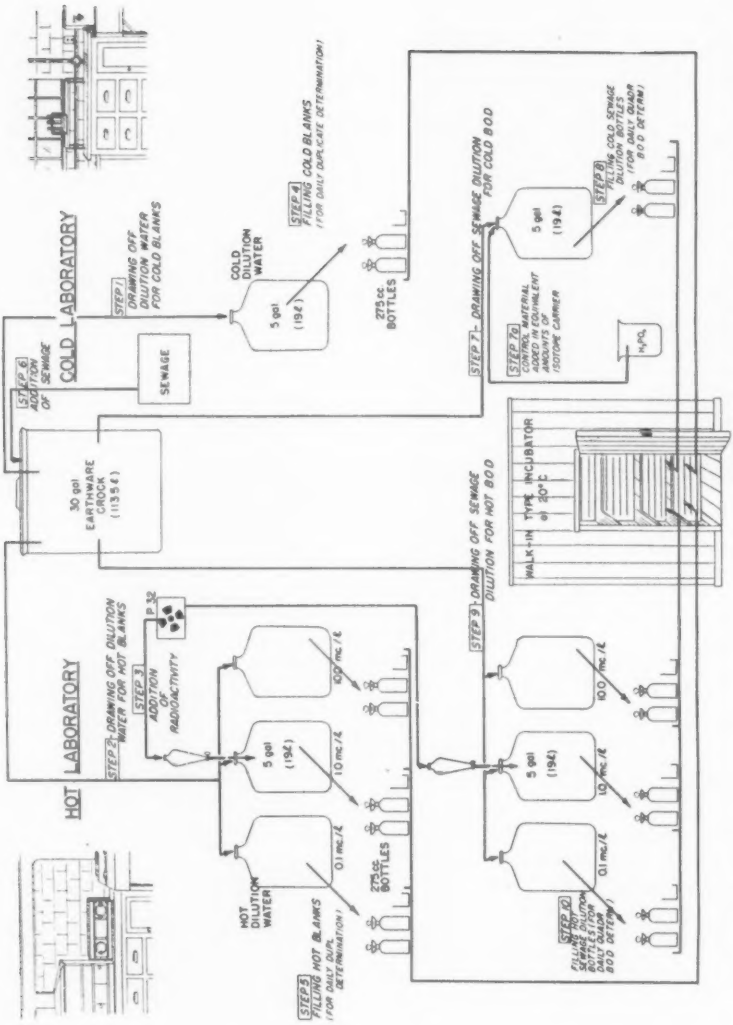
HOT LABORATORY
COLD LABORATORY
STEP 1 DRAWING OFF DILUTION WATER FOR COLD BLANKS
STEP 2 DRAWING OFF DILUTION WATER FOR HOT BLANKS
STEP 3 ADDITION OF RADIOACTIVITY
STEP 4 FILLING COLD BLANKS (FOR DAILY DUPLICATE DETERMINATION)
STEP 5 FILLING HOT BLANKS (FOR DAILY DUPL. DETERMINATION)
STEP 6 ADDITION OF SEWAGE
STEP 7 DRAWING OFF SEWAGE DILUTION FOR COLD BOD
STEP 7a CONTROL MATERIAL ADDED IN EQUIVALENT AMOUNTS TO SEWAGE (SODIUM CARRIER)
STEP 8 FILLING COLD SEWAGE DILUTION BOTTLES (FOR DAILY DUPLICATE BOD DETERMINATION)
STEP 9 DRAWING OFF SEWAGE DILUTION FOR HOT BOD
STEP 10 FILLING HOT SEWAGE DILUTION BOTTLES (FOR DAILY DUPLICATE BOD DETERMINATION)
30 gal EARTHWARE CROCK (113541)
SEWAGE
COLD DILUTION WATER
HOT DILUTION WATER
5 gal (19l)
275 cc BOTTLES
0.1 mc/l
10 mc/l
60 mc/l
P 32
WALK-IN TYPE INCUBATOR at 20°C

FIGURE 5.—Flow diagram of laboratory procedure for each run for both "cold" and "hot" laboratories.

tion water was standardized for all runs. After the aeration period of one week the contents of the carboys were emptied into a large crock of 30-gal. capacity, stored for another week to induce equilibrium, and stirring practiced to assure uniformity of blending.

The dilution water was then split for further processing in the "hot" and "cold" laboratories (see Figure 5). Each step was performed in parallel fashion between the two laboratories. The B.O.D. run with ordinary domestic sewage performed in the "cold" laboratory as a control was kept completely separate from the radioactive sewage runs, which were dosed to the levels of 0.1, 1.0, and 10.0 millicuries per liter with radiophosphorus (P^{32}). To the non-radioactive dilution water an equivalent amount of normal orthophosphate was added, equivalent to the amount of carrier added along with the radiophosphorus. This amounted to about 0.2 p.p.m. of H_3PO_4, a small amount when compared with the phosphate buffer and the phosphates initially present in the sewage. The actual amount of radiophosphorus and carrier added amounted to 35 ml. for the highest concentration used.

The exact amount of isotope was remote-pipetted from the "high-intensity" hood into an Erlenmeyer flask, and then transported in a lead-lined container (see Figure 6) to the laboratory bench where the B.O.D. bottle filling unit was located. The entire contents were poured into a shielded separatory funnel, raised by a pulley system (see Figure 4), and the combined isotope and dilution water concentrate flowed by gravity back into the carboy.

To prevent the non-radioactive sewage from being irradiated during the seven-day period inside the incubator, Plexiglass shielding was placed between the trays containing the "hot" and "cold" bottles.

To test the immediate dissolved oxygen content of the dilution water, two bottles each were filled with the top and the final portion of water in the carboy. Thus, any stratification of dissolved oxygen was observed by four dissolved oxygen determinations available on the dilution water for zero day. For the remaining seven days, two daily dilution water blanks were tested for dissolved oxygen content; that is, two blanks for each of the concentrations of isotope, as well as the control incubation.

The next step in the over-all procedure (see Figure 5) was preparation of the sewage dilution. After considerable preliminary investigations (13), a 4 per cent dilution was chosen as the most suitable, reliable, and reproduci-

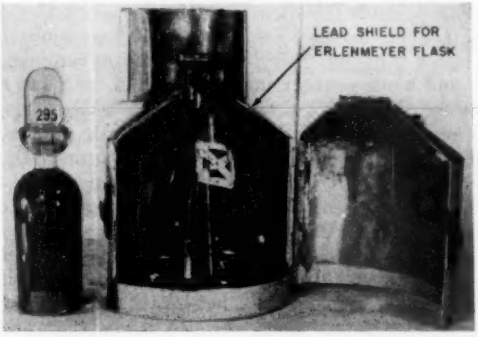

FIGURE 6.—Lead-shielded Erlenmeyer flask for transporting radioactive solutions and specially adapted B.O.D. bottle used for 7-day or longer incubation periods.

ble dilution for further experimentation, based mainly on the 40 to 70 per cent oxygen content depletion criteria in five days, according to Standard Methods (15).

One of four carboys went into the cold laboratory for the control B.O.D.'s; the other three were processed in the tracer laboratory in identical manner as described before. Daily B.O.D. determinations were carried out in quadruplicate. Immediately after the bottles were stoppered and capped they were incubated at 20° ± 1° C.

On each day, four B.O.D. bottles and two blanks, for each of the three levels of radioactivity studies, were taken from the incubator for dissolved oxygen determinations. To the B.O.D. and blank bottles the Winkler reagents were added by means of three Caulifield pipettors. The bottles were shaken through the permanently fastened gauntlet-type gloves in the "Berkeley" type dry box.

A trap door between the mixing unit and the titration unit (Unit III) permitted the bottles to be moved directly over for titration with standard sodium thiosulfate without being brought outside, which made it possible for the operator's clothes or immediate floor-space beneath to remain free of radioactivity.

The excess liquid in the B.O.D. bottles, above the 200 ml. required for titration, was dumped inside the titration unit into a 1½ in. drain, from which it flowed into a 2 in. pipe, then through the trap and house connection into the street sewer. As a continuous flow of water was maintained, the factor of dilution for the 75 ml. wasted from each bottle was very great. It is estimated that the maximum concentration ever discharged was well below 2 microcuries per liter, representing a factor of dilution of 50, 500, and 5,000 for the 0.1, 1.0, and 10.0 millicuries per liter levels, respectively, under study. Each bottle was immediately flushed inside this unit by means of a foot-pedal controlled spigot. The B.O.D. bottles were then placed over a water-jet washer inside the stainless steel double sink, washing six bottles simultaneously for 1 to 2 hr.

Decontamination was practiced with a solution of Na_2HPO_4. After the initial thorough tap-water rinse, these bottles were filled with Na_2HPO_4 solution and left to stand. Their stoppers were treated similarly with Na_2HPO_4 in large beakers. This method, depending on the favorable exchange of P^{31} for P^{32}, proved to be very efficient. Originally the bottles read up to 20 milliroentgens per hour at a distance of 0.5 in., but after a 24- to 48-hr. soak in Na_2HPO_4 their activity was reduced to 0.2 to 0.5 milliroentgen per hour. The phosphate solution could be used over again.

The same type of laboratory techniques and procedures was followed for the B.O.D. control runs, made in parallel but with no radioactivity, and excepting shielding, remote control handling, and decontamination.

Evaluation of the B.O.D. Reaction Characteristics

B.O.D. values of the sewage in each incubation bottle were computed in accordance with Standard Methods (15). In determining the course of oxygen depletion in the dilution water it was necessary to develop a procedure for obtaining daily values of this depletion, as B.O.D.'s were obtained for periods of incubation ranging from 1 through 7 days, and for some runs through 20 days. The method adopted was to run daily duplicate blanks in parallel with the B.O.D. bottles. Depletions for any run were then plotted on graph paper and the straight line of best fit evaluated by the method of least squares. From this graph, average daily depletions could be read with accuracy. The net loss of dissolved oxygen rarely exceeded 0.5 p.p.m. in seven days, and usually ranged from 0.2 to 0.3 p.p.m. in five days.

Statistical evaluation of the significance of radioactive isotopes in changing the biochemical oxidation reactions could best be accomplished by performing statistical operations on the parameters of ultimate first-stage B.O.D., L; the reaction velocity constant, k; and the 5-day B.O.D. for each run. The sanitary engineering profession has generally accepted the interpretation of the composite reactions involved in the oxidation of the complex organic matter in sewage as a first-order reaction.

This reaction is usually expressed by the differential equation:

$$-\frac{dy}{dt} = k(L - y)$$

in which y is the amount of B.O.D. at time t, in p.p.m.; L is the ultimate first-stage B.O.D., in p.p.m.; and k is the proportionality or reaction velocity constant, per unit time.

Values of y were obtained from the B.O.D. tests as previously discussed. The application of these values and their corresponding times, t, to the above equation can be made in a number of ways, the most accurate method being the method of least squares. The authors chose to adopt a simpler and yet quite accurate method suggested by Moore, Thomas, and Snow (16) and known as the "Method of Moments." Recently, in a similar study, it was found that in comparing the moment method with the slope method, the former actually gave better fits of y vs. t than the latter in 8 out of 10 runs (17).

The moment method is predicated on fitting a curve of a stated type to the given data in such a manner that the moments of selected points on the curve about the origin are equal to the corresponding moments of the observed data. The method has proved to be of inestimable value in this research.

Results

The results obtained from 37 runs are shown in the form of the computed parameters k (reaction velocity constant), L (first-stage B.O.D. value), and 5-day B.O.D. values. These were obtained from the individual observations in accordance with the methods and procedures previously outlined.

TABLE I.—Reaction Velocity Constants, k, with Various Levels of Radioactivity (as P^{32})

Run Number	Sewage Dilution (%)	Value of k			
		Cold	Radioactivity (mc./l.)		
			0.1	1.0	10.0
1	4	0.200	—	0.250	—
2	5	0.217	—	0.257	—
3	5	0.318	—	0.198	—
4	4	0.150	—	0.213	—
5	4	0.117	—	0.222	—
6	4	0.201	—	0.355	—
7	4	0.176	—	0.192	—
8	4	0.157	—	0.205	—
9	4	0.158	—	0.149	—
10	4	0.166	—	0.173	—
11	4	0.155	—	0.157	—
12	4	0.159	—	0.171	—
13	4	0.145	—	0.167	—
14	4	0.175	—	0.200	—
15	4	0.157	0.145	0.158	0.161
16	4	0.132	0.149	0.122	0.128
17	4	0.144	0.146	0.138	0.153
18	5	0.134	0.168	0.149	0.147
19	4	0.131	0.159	0.168	0.053
20	5	0.187	0.156	0.165	0.187
21	4	0.163	0.180	0.173	0.177
22	4	0.136	0.125	0.128	0.142
23	4	0.140	0.154	0.136	0.168
24	4	0.163	0.180	0.177	0.160
25	4	0.163	0.135	0.143	0.171
26	5	0.164	0.177	0.170	0.108
27	4	0.148	0.173	0.170	0.087
28	4	0.111	0.124	0.131	0.101
29	4	0.176	0.181	0.168	0.164
30	4	0.152	0.161	0.138	0.123
31	4	0.186	0.192	0.195	0.216
32	4	0.233	0.206	0.183	0.164
33	4	0.234	0.257	0.246	0.220
34	4	0.299	0.243	0.223	0.227
35	4	0.223	0.251	0.241	0.242
36	4	0.192	0.181	0.197	0.188
37	2.5	0.175	0.152	0.148	0.130

Table I shows the k-values for the ordinary sewage (not inoculated with radiophosphorus), as compared to the values obtained with sewage dilutions containing 0.1, 1.0, and 10.0 millicuries per liter of radiophosphorus (P^{32}).

The per cent dilutions are also indicated for each run, generally being maintained at 4 per cent.

It will be noted that the first 14 runs were performed at only one level of radioactivity; namely, 1.0 millicurie per liter. As the personnel became more familiar with the laboratory, handling, and counting techniques, and the research staff was increased, it became possible to make simultaneous runs at three levels of activity. The level of 10.0 millicuries per liter was selected to bear out any trends of the waste in streams, as it has been demonstrated that certain of the algae do concentrate radioactivity by a factor of 10^5.

Table II shows the computed values of the ultimate first-stage B.O.D. for the "cold" and "hot" sewages. These values represent the parameter L for each series of investigations, as computed by the two-moment method.

TABLE II.—Ultimate First-Stage B.O.D., L, with Various Levels of Radioactivity (as P^{32})

Run Number	Value of L (p.p.m.)			
	Cold	Radioactivity (mc./l.)		
		0.1	1.0	10.0
1	57.7	—	56.1	—
2	80.2	—	75.3	—
3	101.5	—	101.5	—
4	129.8	—	124.1	—
5	38.5	—	32.1	—
6	67.1	—	69.1	—
7	114.2	—	110.7	—
8	108.4	—	87.9	—
9	103.3	—	96.8	—
10	169.1	—	168.1	—
11	127.1	—	125.5	—
12	156.1	—	147.3	—
13	130.3	—	125.4	—
14	137.1	—	130.1	—
15	129.0	127.9	120.1	123.1
16	115.7	106.6	115.3	115.2
17	158.7	146.2	156.5	149.4
18	58.7	51.7	53.7	55.8
19	136.3	130.5	126.5	195.2
20	155.4	157.0	159.3	149.1
21	151.2	155.2	155.4	151.8
22	139.0	139.3	139.0	130.0
23	116.4	105.6	116.5	101.5
24	150.3	142.3	142.4	142.5
25	120.5	124.3	123.2	112.7
26	134.5	127.8	129.8	146.2
27	135.4	125.2	128.9	150.6
28	159.0	149.8	143.7	150.1
29	137.2	139.7	142.5	137.3
30	118.1	115.0	119.9	123.6
31	112.5	187.8	141.7	148.1
32	109.2	120.9	125.4	121.3
33	121.9	118.7	123.8	126.9
34	115.8	116.7	115.9	113.8
35	134.3	102.8	103.6	103.3
36	141.3	135.6	134.1	136.3
37	113.2	117.0	121.3	134.2

TABLE III.—5-Day B.O.D., $y_{(t=5)}$, with Various Levels of Radioactivity (as P^{32})

Run Number	5-Day B.O.D. (p.p.m.)			
	Cold	Radioactivity (mc./l.)		
		0.1	1.0	10.0
1	50.3	—	49.1	—
2	73.2	—	67.4	—
3	96.0	—	90.8	—
4	108.4	—	115.9	—
5	26.4	—	26.4	—
6	59.8	—	78.6	—
7	102.4	—	100.2	—
8	92.7	—	79.3	—
9	84.9	—	81.6	—
10	142.0	—	144.3	—
11	104.6	—	107.1	—
12	129.3	—	128.2	—
13	106.3	—	109.0	—
14	115.7	—	117.4	—
15	107.4	104.3	100.1	103.9
16	92.8	87.4	88.4	89.1
17	128.7	118.4	125.9	125.5
18	44.7	46.3	44.3	45.6
19	105.0	109.1	109.6	93.7
20	136.4	129.3	134.4	131.3
21	128.9	139.2	130.9	138.6
22	110.3	108.8	107.4	106.2
23	90.9	88.7	87.7	87.8
24	128.3	125.3	121.1	123.6
25	98.6	97.0	97.1	96.7
26	113.8	109.5	109.7	106.5
27	109.8	107.1	112.1	99.7
28	112.2	114.5	113.3	104.3
29	114.7	122.7	120.9	115.7
30	100.8	99.5	97.1	95.6
31	99.3	166.1	123.7	134.4
32	104.0	108.2	105.1	100.7
33	112.4	108.8	112.4	114.9
34	108.9	109.4	103.1	106.2
35	117.7	97.2	95.0	96.7
36	120.5	116.3	115.1	118.0
37	97.9	97.5	96.9	106.1

Table III presents the 5-day B.O.D. (y) values. These were calculated directly from the laboratory data according to Standard Methods (15).

TABLE IV.—"t" Test for the Significance of Differences in k-Values Between Cold and Hot[1] Sewages

Run Number	k_c	k_h	$d = k_h - k_c$	$d^2 = (k_h - k_c)^2$
15	.157	.145	−0.012	0.000144
16	.132	.149	+0.017	0.000289
17	.144	.146	+0.002	0.000004
18	.134	.168	+0.034	0.001156
19	.131	.159	+0.028	0.000784
20	.187	.156	−0.031	0.000961
21	.163	.180	+0.017	0.000289
22	.136	.125	−0.011	0.000121
23	.140	.154	+0.014	0.000196
24	.163	.180	+0.017	0.000289
25	.163	.135	−0.028	0.000784
26	.164	.177	+0.013	0.000169
27	.148	.173	+0.025	0.000625
28	.111	.124	+0.013	0.000169
29	.176	.181	+0.005	0.000025
30	.152	.161	+0.009	0.000081
31	.186	.192	+0.006	0.000036
32	.233	.206	−0.027	0.000729
33	.234	.257	+0.023	0.000529
34	.299	.243	−0.056	0.003136
35	.223	.251	+0.028	0.000784
36	.192	.181	−0.011	0.000121
37	.175	.152	−0.023	0.000529
$n = 23$			$\Sigma d =$ +0.052	$\Sigma d^2 =$ 0.011950

$$\bar{d} = +0.002260869$$

$$(\Sigma d)^2 = 0.002704$$

$$\frac{(\Sigma d)^2}{n} = 0.000117565$$

$$s_{\bar{d}} = \sqrt{\frac{\Sigma d^2 - \frac{(\Sigma d)^2}{n}}{n(n-1)}} = \frac{0.011832}{506} = 0.0000233834$$

$$s_{\bar{d}} = 0.0048356$$

$$t = \frac{\bar{d} - \bar{d}'}{s_{\bar{d}}} = \frac{0.0022608}{0.0048356} = 0.46753$$

Degrees of freedom = 22
Probability = $P = 0.65912$, say 66 per cent[2]

[1] 0.1 millicurie of P^{32} per liter.

[2] This is based on the hypothesis that the difference between reaction velocity constants is zero. The probability of a difference as great or greater than that observed between the calculated k-values would occur 66 per cent of the time due to chance factors alone. Therefore no significant difference is indicated.

Statistical Analysis of Results

The objective of performing statistical analyses on the results of parallel runs on the biochemical oxidation of sewage with and without the presence of radioactive phosphorus (P^{32}) is to determine the statistical significance of any differences in the parameters being studied. The comparison in each case was made between the values for the "cold" runs versus the values for the "hot" runs at each level of activity and for each parameter noted. Student's "t" distribution and the "t" test for significance were used. Table IV is presented to show the "t" test for a typical calculation, in this case the k-values between the "cold" sewages and those containing 0.1 millicurie per liter.

As in most cases where biochemical reactions are involved, the test for significance is based on the 95 per cent level. Thus, with the use of the "t" distribution, an average of the differences between "cold" and "hot" sewage is considered significant only when such stated difference can be expected to occur by chance alone less than 5 per cent of the time. For example, the calculations in Table IV yield a value of $P = 0.6591$. This indicates that 66 per cent of the time the average of the differences of the k-values between the

$$\left(\bar{d} = \frac{\Sigma(k_h - k_c)}{n} = 0.0023\right)$$

"hot" and "cold" sewages with 0.1 millicurie per liter of P^{32} added can be expected, due to chance factors alone, to be as great as 0.0023 for 23 runs. Therefore, the slight differences in k-values are not significant for these runs.

Similar statistical analyses were performed on the other results presented in Tables I, II, and III. These analyses are summarized in Table V.

TABLE V.—Average Differences[1] and the Probability (P) of their Occurrences by Chance Alone for k, L, and 5-Day B.O.D. Values at Various Concentrations of Radioactivity

Radioactivity (mc./l.)	No. of Runs	Values of k		Values of L		5-Day B.O.D.	
		$\bar{d} = \frac{\Sigma(k_h - k_c)}{n}$	P (%)	$\bar{d} = \frac{\Sigma(L_h - L_c)}{n}$	P (%)	$\bar{d} = \frac{\Sigma(y_h - y_c)}{n}$	P (%)
0.1	23	+0.0023	65.9	−0.9391	81.2	+1.23	70.9
1.0	37	+0.0092	21.4	−2.5811	11.3	−0.77	54.4
10.0	23	−0.0142	5.4	+2.3652	54.1	−1.92	37.5

[1] $\bar{d}$ = Hot-Cold.
[2] As P^{32}.

Discussion of Results

The summary of the results of statistical analyses in Table V represents thousands of individual B.O.D. tests on normal domestic sewage with and without the presence of radioactivity. Throughout the research program efforts were directed toward eliminating as many variables as possible in order that any real differences could be attributed directly to the influence of radioactivity.

The variability of the domestic sewage could not be controlled because one of the objectives of this research program was to observe the effects of radioactivity on an ordinary domestic sewage. Even though the sewage samples were taken at 9 : 00 A.M. on Wednesdays (13) (14) of each week of experimentation, the 5-day B.O.D. values varied from 45 to 142 p.p.m. over a period of 18 months. These variations can be handled readily by means of the methods of statistical analysis utilized, as the statistical operations were conducted among the observed differences for each run. Averages were only taken of these differences and not of the average values of k, L, and 5-day B.O.D.

Referring to Table V, it is evident that no significant differences were noted in the k-values obtained at any concentration of radioactivity up to 10.0 millicuries of P^{32} per liter of sewage dilution. Only when the average difference in k-values exceeds a value which can be expected to occur by chance alone less than 5 per cent of the time can the difference be considered significant; that is, attributable to some other variable than mere chance variation through the vagaries of biochemical reactions. Thus, these results indicate that up to 10 millicuries per liter of beta radiation from phosphorus (as P^{32}) will not have any significant effect on the the rate of biochemical oxidation of this domestic sewage.

Considering next the ultimate first-stage B.O.D. and the 5-day B.O.D. values, the results likewise indicate that no significant differences may be noted between radioactive and non-radioactive biochemical oxidation reactions. The results for the first-stage L-value show that as large or larger a difference as was obtained with the presence of 0.1, 1.0, and 10.0 millicuries per liter should occur 81, 11, and 54 per cent of the time, respectively, due to chance factors alone.

When the 5-day B.O.D. values are examined, the same picture presents itself again. The probabilities for the average differences as found to be purely due to chance factors are 71, 54, and 38 per cent for the three levels of radiophosphorus under investigation; namely, 0.1, 1.0, and 10.0 millicuries per liter.

As additional data became available it was periodically analyzed, until the results herein presented were obtained. During the interim period, the only valid interpretation of the statis-

tical results was that not enough runs were made to reach valid conclusions. As the vagaries of any natural phenomenon increase, experimental errors also increase and a greater number of observations is needed to determine the significance of differences. The B.O.D. test is certainly one of those vagaries familiar to sanitary engineers, yet whose need has been well established as a quantitative measure of pollutional characteristics of sewages and streams.

Love (18) has recently pointed out that the radioactivity of uncontaminated natural water does not normally exceed 10^{-5} microcurie per liter, although a value of 4.8×10^{-4} microcurie per liter was reported for the public supply in Barcelona, Spain. For water in which people may be submerged, as in swimming or bathing waters, the tentative level of 10^{-4} microcurie per liter (19) has been suggested by the National Committee on Radiation Protection. These present tolerance levels are far below any value of radioactivity which might influence the biochemical oxidation of organic matter in sewage and the natural processes of the purification of streams, as the levels of the experiments conducted were in the order of 10^{8} greater than the value of 10^{-4} microcurie per liter.

Conclusions

On the basis of the investigations reported in this paper, the following conclusions may be drawn:

1. It has been successfully demonstrated that ordinary tests of sanitary engineering significance may be carried out under radioactive conditions when the proper precautions and safety measures are observed.

2. Radioactive phosphorus (P^{32}) when present in concentrations at or below 10 millicuries per liter exerts no significant effect on the following parameters in the first stage of the biochemical oxidation of sewage:

   a) The reaction velocity constant of biochemical oxidation, k.
   b) The ultimate first-stage B.O.D. value, L.
   c) The 5-day B.O.D., $y_{t=5}$.

3. These results give further evidence that the tentative tolerance level of 10^{-4} microcurie per liter is safe from the standpoint of the biochemical oxidation of organic matter in streams or other watercourses.

Acknowledgments

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PLAN NEEDS! ORDER EARLY!

The present situation on critical materials will justify extra thought and planning for equipment repair and replacement, as well as for new and extension construction. An inventory of all anticipated needs, with a schedule of their order of importance, is certainly a "must" at this time.

In placing orders for materials and equipment it must be recognized that immediate delivery cannot be anticipated; the same kind of delays as were experienced during the last national emergency must be expected. At the moment, priorities are applicable only to defense orders. However, that situation may be changed overnight.

In recognition of the seriousness of any blanket restrictions on materials, the Federation is presently active in making suitable contacts at the federal level to maintain the availability of the supplies and equipment needed for construction, operation, and maintenance in the wastes disposal field.

DISINFECTION OF SEWAGE WITH CHLORINE*

III. FACTORS AFFECTING COLIFORMS REMAINING AND CORRELATION OF ORTHO-TOLIDINE AND AMPEROMETRIC CHLORINE RESIDUALS

By H. Heukelekian and Robert V. Day

In the first paper of this series (1), results of laboratory experiments on the chlorination of sewage and effluents were presented to determine whether a certain stipulated residual of coliform organisms could be obtained on the basis of chlorine dosage alone. In a second paper (2), the results of plant studies on the method of mixing chlorine with the sewage on the uniformity of distribution of residual chlorine in the contact tank were presented. The present paper deals with:

1. The number of coliform organisms remaining in plant effluents with various methods of mixing.
2. The effect of contact time, dosage, and chlorine residual on the residual coliform organisms.
3. The relationship between orthotolidine and amperometric chlorine residuals.

Methods and Procedure

Two primary-type sewage treatment plants were selected for study. The chlorine contact tank of plant A is provided with a vertical mixing compartment 18 in. square and 10 ft. deep, into which the chlorine hose is placed 2 ft. below the water level. A baffle extending from the water surface to within 3 ft. of the bottom separates this compartment from the first channel of the contact tank. The sewage enters the contact tank through the bottom and travels through the 11 channels in which the contact tank is divided by around-the-end type baffles. The tank is 10 ft. deep, 11 ft. wide and 28.5 ft. long and provides a 60-min. contact period with the sewage flows encountered.

Two sets of experiments were conducted at this plant to determine the effect of mixing on the coliform residuals obtained. Two series of studies on two different days were made with the chlorine, applied according to design and normal operation as described above. This is referred to as "mixing." Two additional series were run on two different days with the chlorine hose removed from the mixing compartment and placed at the beginning of the third channel of the contact tank. The chlorine hose was submerged 5 ft. below the surface, pointing downward.

The chlorine feed was set at a constant rate, and influent and effluent samples were taken every half hour during the day, the mixing procedure remaining the same during this period. The period covered during the day was from 9 A.M. to 4 P.M., during which time 15 sets of influent and effluent samples were taken. In the first series, the effluent samples were taken at the end of the contact tank. To shorten the contact period the samples in the second series were taken at approximately the point of 30-min. contact when the normal mixing procedure was used. With this mixing procedure uniform distribution of chlorine could be obtained at any depth in the tank after 30-min. contact (2). When the mixing

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procedure was artificially altered by placing the hose in the channel of the contact tank, distribution of chlorine in the tank was so poor that representative samples could not be taken at any depth within the tank and, therefore, samples were taken at the effluent end of the tank.

The second study was conducted in plant D. The purpose of this study was to determine the effect of chlorine dosage, chlorine residual, and contact time with the existing facilities of mixing on the achievement of a certain stipulated number of coliform organisms after treatment by sedimentation.

The chlorination facilities at this plant consist of a shallow mixing compartment (3 ft. square and 4 ft. deep) with the chlorine hose placed at the bottom. The flow from the two clarifiers on opposite sides of the contact tank is collected in channels meeting at the mixing compartment, creating a turbulence. The flow passes under a baffle (1 ft. from the bottom) and then over a weir into the first channel of the contact tank. Around-the-end type baffles divide the contact tank into 5 channels. The tank is 4 ft. deep, 7.5 ft. wide and 72 ft. long. The approximate detention time is 30 min.

The dosage of chlorine was determined by recording the hourly flows during the period of experimentation and recording the amount of chlorine gas used during that period. The points of different contact times within the contact tank were computed, using an average flow for the period of experimentation. The procedure consisted of taking samples of the influent and then taking samples in the contact tank at the various contact times, the object being to follow one slug of sewage through the contact tank.

The M.P.N. of coliform organisms was determined on all samples by initial enrichment on lactose broth followed by confirmation on brilliant-green bile broth. Triplicate tubes of each dilution were made, the M.P.N. obtained from probability tables, and results expressed as M.P.N. per ml. on the basis of the confirmed test. The samples for determination of coliform organisms were taken in sterile bottles containing sufficient sodium thiosulfate to neutralize the chlorine.

The chlorine residuals for the study dealing with the effect of mixing at plant A were determined amperometrically. Those at plant D were determined by both ortho-tolidine and amperometric methods.

Effect of Mixing on Coliforms

The comparison of the effect of mixing on the number of residual coliform organisms is made on the basis of 30 samples each with and without mixing. On two different days, 15 samples were taken with mixing and a similar number without mixing. The average,

TABLE I.—Comparison of the Effect of Mixing and No Mixing on the Residual Coliform Organisms After Chlorination in Plant A

	With Mixing			Without Mixing		
	Min.	Max.	Av.	Min.	Max.	Av.
No. samples, total	—	—	30	—	—	30
Flow (gal./30 min.)	9,000	26,500	13,700	7,100	26,000	13,000
Contact time (min.)	23	77	46	37	90	46
Chlorine dosage (p.p.m.)	9.1	23.3	15	96	29	14.6
Chlorine residual (p.p.m.)[1]	0	5	2.4	0	7.1	2.9
Coliforms, initial (M.P.N./ml.)	45,000	1,100,000	307,500	75,000	1,100,000	359,000
Coliforms, residual (M.P.N./ml.)	2.5	25,000	2,135	7.5	25,000	80,750

[1] Amperometric.

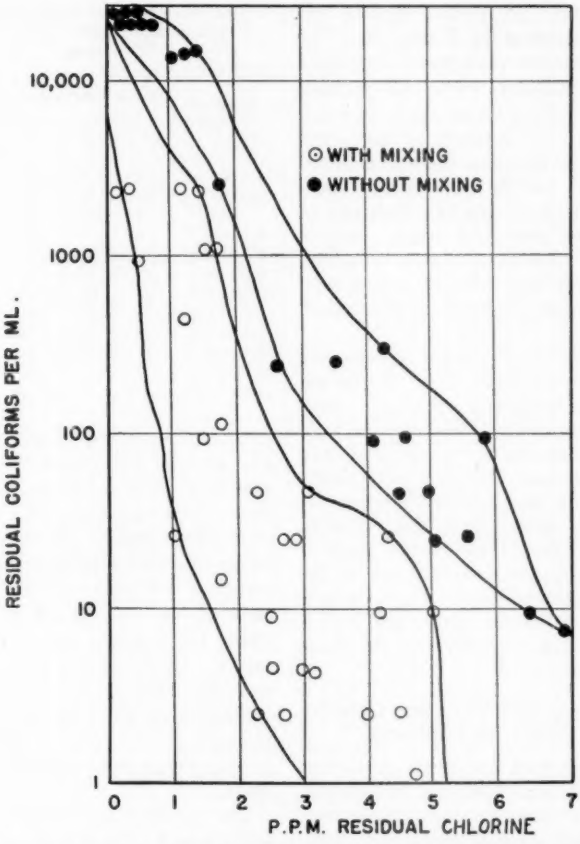

FIGURE 1.—Variations in the achievement of various coliform residuals at different amperometric residuals with and without mixing.

minimum, and maximum results are presented in Table I. The flows and contact times were nearly alike for the experiments with and without mixing on the basis of average values. The minimum and maximum flows and contact times were somewhat divergent during the experiment with mixing from that without mixing. Similarly, the chlorine dosages and residuals were also close for the mixing and no mixing experiments. The maximum residual during the experiment without mixing was appreciably higher than during the series with mixing. The minimum chlorine residual in each case was zero. The average numbers of coliform organisms before chlorination were also very close, as were the minimum and maximum. Despite the close similarities of the conditions of the experiment, the average, as well as the minimum numbers of coliform organisms without mixing were significantly higher than those with the normal mixing provided for at this plant.

The results of residual coliform numbers in the individual samples obtained

in this study are plotted against the residual chlorine in Figure 1. The figure shows the variation between the different samples with and without mixing at different amperometric residuals. It is of interest to note that despite the variations there is no overlapping of results between the series with and without mixing. It is also of interest to note that there were a greater number of cases with very high residual coliforms without mixing than with mixing at the lower chlorine residuals.

In Table II the same results are grouped on the basis of certain ranges of chlorine residuals. For any range of chlorine residual the average minimum and maximum numbers of coliform organisms are decidedly lower with mixing than without mixing. It should be noted that the chlorine residuals reported are on the basis of amperometric titration and not on the basis of ortho-tolidine. Amperometric residuals, as shown later, are higher than would be the case on the basis of ortho-tolidine.

Effect of Contact Time and Chlorine Residuals on Coliforms

The studies on the effect of contact time and chlorine residuals on the number of residual coliform organisms were made under normal operating conditions in plant D. Chlorination facilities at this plant were described under "Methods and Procedure." The studies entailed 94 tests over a period of months with different chlorine residuals. For each individual test, 1.5, 10, 15, and 30-min. contact times were studied. Only a summary of all the data can be presented here. The results are averaged on the basis of a range of ortho-tolidine residuals. The range of residuals and the number of tests within each range are given in Table III. It was not possible to obtain an equal number of cases in each residual chlorine range, but, with the exception of the extremely low and high ranges, there are sufficient cases in each group to be statistically significant.

The numbers of coliform organisms are plotted (Figure 2) against the average ortho-tolidine residuals of each range. The 1-min. contact time results are left out because effective disinfection could not be obtained with even the highest residuals obtained. The

TABLE III.—Range of Ortho-tolidine Chlorine Residuals and Number of Tests for Each Range

Range of Residuals (p.p.m.)	No. of Tests for Contact Time (min.)				
	1	5	10	15	30
0	1	4	7	11	17
0.05 to 0.1	11	12	13	11	8
0.15	4	5	2	3	9
0.2 to 0.3	9	7	12	13	11
0.4 to 0.5	12	13	9	15	18
0.6 to 0.7	10	10	16	13	10
0.8 to 1.0	21	22	15	10	6
1.1 to 1.5	10	5	5	7	4
1.6 to 2.0	9	9	9	7	8
2.1 to 3.0	4	4	2	1	1
3.1 to 4.0	3	2	2	2	1

TABLE II.—Comparison of the Effect of Mixing and No Mixing on the Residual Coliform Organisms (M.P.N. per Ml.) at Different Ranges of Amperometric Chlorine Residuals

Range of Residuals (p.p.m.)	Mixing				No Mixing			
	No. of Cases	Min. (M.P.N./ml.)	Max. (M.P.N./ml.)	Av. (M.P.N./ml.)	No. of Cases	Min. (M.P.N./ml.)	Max. (M.P.N./ml.)	Av. (M.P.N./ml.)
0 to 1	5	950	2,500	11,190	10	25,000	25,000	25,000
1 to 3	16	2.5	2,500	500	6	250	11,000	6,000
3 to 5	8	0.9	25	10.8	7	45	250	155
5 to 7	1	—	—	9.5	7	7.5	110	33

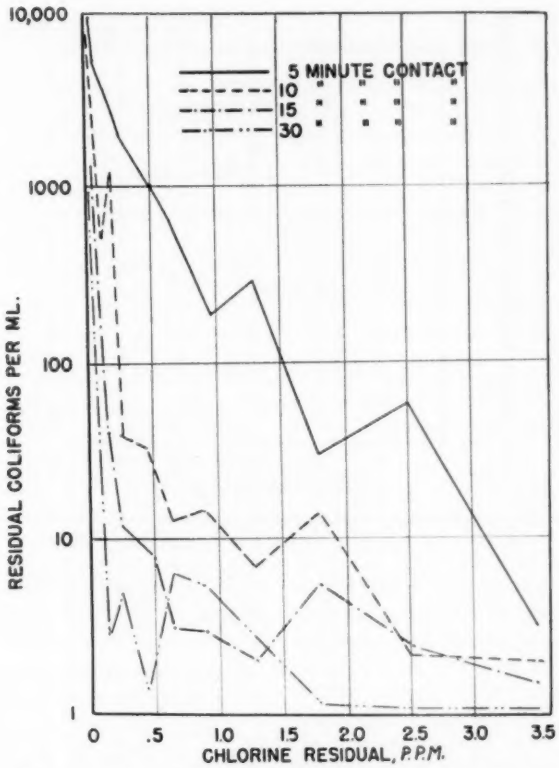

FIGURE 2.—Effect of various ortho-tolidine residuals and contact time on the residual coliform organisms.

results emphasize again the importance of contact time and chlorine residuals in bringing about effective disinfection. With 1-min. contact time, an average ortho-tolidine residual of 3.5 p.p.m. was required to bring the coliform numbers to 3.0 per ml., whereas with 30-min. contact time similar results could be achieved with only about 0.15 p.p.m. of residual chlorine. The intermediate contact times of 10 and 15 min. gave results which lie in between these extremes.

It is often more significant to know how frequently a certain stipulated number of coliform organisms can be obtained with a given chlorine residual and contact time than to know the average number of coliforms obtained on the basis of a certain number of tests. One of the more rigid effluent standards of 2.5 coliforms per ml. was selected as a basis of analysis of the results. The percentages of the cases that met requirement for various contact periods and chlorine residuals are plotted in Figure 3. It will be seen that a 50 per cent compliance with the stipulated number of coliforms was not obtained with even 30-min. contact time up to 0.15 p.p.m. residual chlorine. Residuals of 0.2 to 0.5 p.p.m. gave about 80 per cent compliance with this standard with 30-min. contact time and only

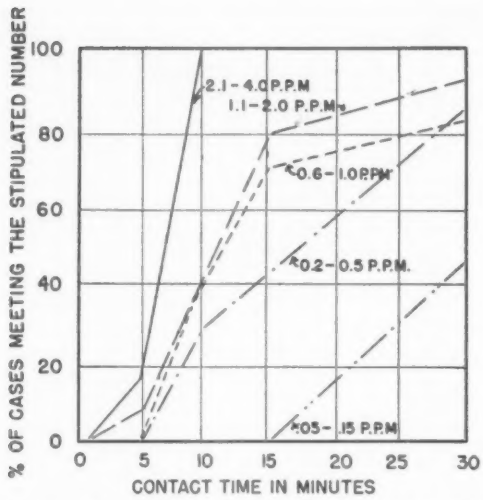

FIGURE 3.—Percentage of cases meeting the stipulated number of coliforms (2.5 per ml.) with various contact times and ortho-tolidine residuals.

40 per cent with 15-min. contact time. In 70 per cent of the cases the stipulated numbers of coliform organisms were achieved with 0.6 to 1.0 p.p.m. residual chlorine after 15-min. contact time and an increase up to 80 per cent was obtained with 30-min. contact time. With residuals of 1.1 to 2.0 p.p.m. the stipulated residual coliforms were obtained in 80 per cent of the cases with 15-min. contact time and 90 per cent with 30-min. contact time. With residuals of 2.1 to 4.0 p.p.m., 100 per cent of the time the coliform numbers were 2.5 per ml. or less after only 10-min. contact time.

It is apparent that for low residuals the compliance increases with contact time, whereas with high residuals the same end result can be accomplished with shorter contact periods (Figure 4). It would appear, therefore, that in the original design adequate contact time should be provided from the standpoint of economy of operation. In existing plants where shorter contact times are available, either due to original design or increased flows, to obtain acceptable effluents with the desired coliform numbers reliance must be placed on higher residuals.

Correlation of Ortho-tolidine and Amperometric Residuals

A mass of data was accumulated from four plants on chlorine residuals as determined by ortho-tolidine and amperometric methods. The number of tests from each plant was as follows:

Plant A	78
Plant D	93
Plant E	135
Plant F	92

The linear correlation of the ortho-tolidine and amperometric residuals was compiled by the method of least squares and plotted (Figure 5). The slopes of the curves for plants D, E, and F are practically the same; the slope of the curve for plant A is entirely different. The curves also show that at least 1.2 to 1.6 p.p.m. of residual as measured by amperometric procedure are needed to produce a measurable ortho-tolidine residual. The rate of increase thereafter for the three

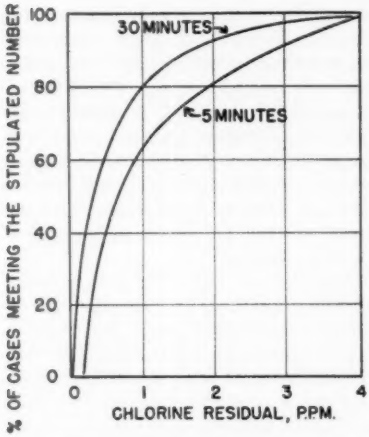

FIGURE 4.—Percentage of cases meeting the stipulated number of coliforms (2.5 per ml.) with various contact times and ortho-tolidine residuals.

sewages is 2 p.p.m. amperometric residual for each p.p.m. increase of ortho-tolidine residual. At plant A, at least 2.15 p.p.m. amperometric residual were needed to produce an ortho-tolidine residual. The sewage at this plant is domestic but stale, due to the fact that there is a detention period of approximately 4 hr. in the sedimentation tanks.

In Table IV, a comparison is given of the M.P.N. of coliform organisms after a 30-min. contact period at plant D with the same magnitude of residual chlorine by the two methods. It illustrates the need of a greater magnitude of amperometric residual than ortho-tolidine residual to achieve the same residual coliform organisms in the effluent. According to Figure 5, a 3.0-p.p.m. amperometric residual is equivalent to a 0.5-p.p.m. ortho-tolidine residual; according to Table IV, equivalent coliform organisms are obtained with a 0.5-p.p.m. ortho-tolidine residual as compared with a 3.0-p.p.m. amperometric residual. Marks, Joiner, and Strandskov (3) also reported on the relationship between ortho-tolidine and amperometric residuals and residual bacterial numbers on the basis of laboratory experiments with sewage from different plants. They concluded that the amperometric method includes chlorine compounds, which exert considerable action against microorganisms and which are not measured by the usual methods of determining residual chlorine. The results presented in Table IV do not support this conclusion.

TABLE IV.—Relationship of Residual Coliform Organisms at Certain Amperometric and Ortho-tolidine Residuals

Chlorine Residuals (p.p.m.)	Residual Coliforms (M.P.N./ml.)	
	Amperometric	Ortho-tolidine
0.5	2,500	2.5
1.0	25	2.0
2.0	2.5	0.9
3.0	2.5	0.9

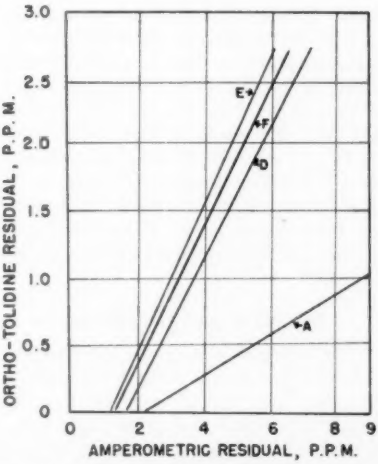

FIGURE 5.—Correlation of ortho-tolidine and amperometric chlorine residuals.

Discussion

The achievement of the purpose of disinfection is based on three elements (1) design, (2) effluent requirements, and (3) operation. In the design the

engineer should take cognizance of the effluent requirements set by the regulatory agency. The operator, on the other hand, has to comply with the requirements of the regulatory agency with the facilities provided to him by the designing engineer.

Adequate design should take into consideration the following features:

1. Chlorinator capacity.
2. Mixing facilities.
3. Contact time.

The chlorinator capacity will depend on the flow, the chlorine demand of the sewage, and the residual number of coliforms to be attained. These are subject to prediction by the engineer. Provision for proper mixing of chlorine with the sewage is very important from the standpoint of economy and efficiency of disinfection. Reliance should not be placed on obtaining adequate mixing in the contact tank where turbulence is at a minimum. Rather, mixing should be obtained in special mixing compartments before the sewage enters the contact tank. A great number of possible means of mixing are available. It does not seem that a special mechanical mixing device is warranted when equally good mixing might be obtained hydraulically. A shallow and a vertical mixing compartment has been found to give adequate mixing as a result of these studies. The submergence of the chlorine hose and the opening of the baffle have also been found to be important factors. The hose in the shallow box should be near the bottom to avoid unnecessary loss of chlorine gas, whereas in the vertical mixing compartment better results will be obtained with the hose away from the bottom near mid-depth. The narrow opening of the baffle assists in giving additional turbulence.

The flow in the contact tank, once proper mixing is obtained, should be of non-turbulent type. If the chlorine is stratified in the entrance of the chlorine contact tank, diffusion under quiescent flow conditions will not bring about uniform distribution. Adequate contact time should be based on operating costs and the stringency of the effluent requirements. It would seem that ample contact time is a good safeguard for accomplishment of the purpose of disinfection, although contact time, no matter how long, will not make up for an actual deficiency of chlorine dosage.

The operator who has a chlorinator of adequate capacity can meet the effluent requirements with the existing facilities only by controlling the chlorine dosage and using the residual chlorine as a guide, unless he has been provided with a chlorinator which feeds according to flow and chlorine demand. If he adjusts the chlorine feeding rate twice a day, once for day flows and once for night flows, he will encounter, with constant dosage during these periods, variable residual chlorine and coliforms. If the effluent requirements were a maximum of 2.5 coliform per ml. 50 per cent of the time and a 30-min. contact period was available, he would have to maintain at least a 0.2-p.p.m. residual at all times to achieve this goal with good initial mixing. If the contact time was only 15 min. he would have to maintain a residual of 0.5 p.p.m. under otherwise similar conditions (Figure 4). If this standard is to be met 75 per cent of the time, the residuals have to be raised to 0.7 p.p.m. with 30-min. contact and to 1.7 p.p.m. with 15-min. contact. If the requirements of coliform density in the effluent were 1 per ml., still higher chlorine residuals would be required.

Summary and Conclusions

The effect of mixing on the residual coliform organisms was investigated by running a series of tests at plant A with the normal design and operating scheme of mixing in a vertical mixing compartment. The effect of contact time and ortho-tolidine residuals on

the numbers of coliform organisms was studied at plant D with the normal method of mixing in a shallow turbulent mixing compartment.

A correlation of ortho-tolidine residuals with amperometric residuals is presented on the basis of a large number of tests in four different plants.

The data obtained warrant the following conclusions:

1. With equal contact times and chlorine residuals, adequate mixing of chlorine with sewage produces coliform numbers of a lower magnitude than when the chlorine is added in the channel of the contact tank.

2. Contact time and residual chlorine are important from the standpoint of achieving the minimum of residual coliform organisms.

3. With low chlorine residuals, contact time plays a greater role than with high chlorine residuals.

4. With ortho-tolidine residuals of 0.05 to 0.15 p.p.m., effluents containing low coliform organisms cannot be produced with a contact time of 15 min.

5. For a stipulated effluent standard of 2.5 coliform organisms per ml., an ortho-tolidine residual of 0.2 to 0.5 p.p.m. will produce 50 per cent compliance with 15-min. contact time and 80 per cent with 30-min. contact time.

6. When the ortho-tolidine residual is 0.6 to 1.0 p.p.m., 70 per cent of the cases will meet the same effluent standard in 15 min.

7. With higher residuals, the compliance increases for each contact time until, with 2.1 to 4.0 p.p.m. ortho-tolidine residual, 100 per cent compliance is obtained with a 10-min. contact time.

8. There is a definite correlation between ortho-tolidine and amperometric chlorine residual. The same relationship does not hold for all sewages. Amperometric chlorine residuals required for equal residual organisms are higher than ortho-tolidine chlorine residuals.

Acknowledgment

The work reported in this paper was supported by a fellowship grant from the Wallace and Tiernan Company, Inc., Newark, N. J.

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CALIFORNIA AND ILLINOIS SEEK SANITARY ENGINEERS

The Civil Service Commissions of both California and Illinois have announced open competitive examinations for sanitary engineers.

Closing date for the California examinations is midnight of March 10, 1951. These examinations are to fill 12 vacancies in the 9 regional offices of the Water Pollution Control Board. Information on the requirements may be obtained from: State Personnel Board, 1015 L Street, Sacramento, Calif.

Closing date for applications for the Illinois examinations is March 23, 1951. Further information and application forms may be obtained from the Illinois Civil Service Commission, 501 Armory Building, Springfield, Ill.

SIMPLIFIED METHOD FOR ANALYSIS OF B.O.D. DATA * —A DISCUSSION

By J. D. Lee

Associate Professor of Civil Engineering, Queen's University, Kingston, Ont., Canada

The paper by Moore, Thomas, and Snow has been read with much interest. The authors are to be commended for adding still another scholarly masterpiece to those already presented by Reed, Fair, Thomas, and Snow.

With the main measure of the polluting characteristic of a waste lying in the B.O.D. test, it seems only reasonable that this test should be the subject of much study. The U. S. Public Health Service and the cooperating agencies are to be congratulated upon the fine work being done, as evidenced through carefully prepared papers in This Journal. It is felt that the discussion by Ruehhoft (p. 1353) is a worth-while contribution, as it deals so aptly with the basic principles of the biochemical oxidation theory.

For a number of years the fourth-year civil engineering students at Queen's University have been performing a B.O.D. test intended to provide an insight into the problem of biochemical oxidation. In this test, a 1.5 per cent dilution of waste and bicarbonate dilution water is mixed in a large bottle in sufficient quantity to fill 12 B.O.D. bottles by siphoning. The bottles are tested for dissolved oxygen by means of the sodium azide modification of the Winkler test at the end of 1, 2, 3 days, etc. Because the object of the experiment is not one of attaining perfection in chemical testing, the results often are not too consistent. Nevertheless, by plotting the results on a mimeographed form (reproduced in Figure 1) it is possible to make a reasonably good determination of the first-stage demand. This form has an abscissa scale proportioned on the basis of $1-10^{-0.1t}$ so that if the data fall on a straight line it is known that $k = 0.1$. The main benefit of the plot is in assessing peculiarities, most of which are apparently associated with a high rate of oxygen demand early in the storage period.

The value of k is readily determined from a semilogarithmic form (Figure 2). This diagram also gives the other constants in the B.O.D. formula.

As a further aid to learning, and valuable as a check on the calculations, is the plotting of the mathematical equation, which is so aptly termed by Ruehhoft as the "curve of best fit," and the observed results, as indicated in Figure 3.

This experiment has been found to be a very useful one from the academic point of view and the method of handling the results is designed for this specific purpose. This discussion is submitted in the belief that the method is, perhaps, somewhat novel and may be useful to others.

The data presented in the figures are taken from page 1347 of the original paper by the authors. Curve A in Figure 1 is a curve of best fit, established by inspection with a view to reading the intercept at 30 days (corresponding with 99.99 per cent B.O.D. removal). This value is 214 from curve A, and 230 from curve B. It is to be noted that curve B might be assumed as suggesting that the main

* As original published in This Journal, **22**, 10, 1343 (Oct., 1950).

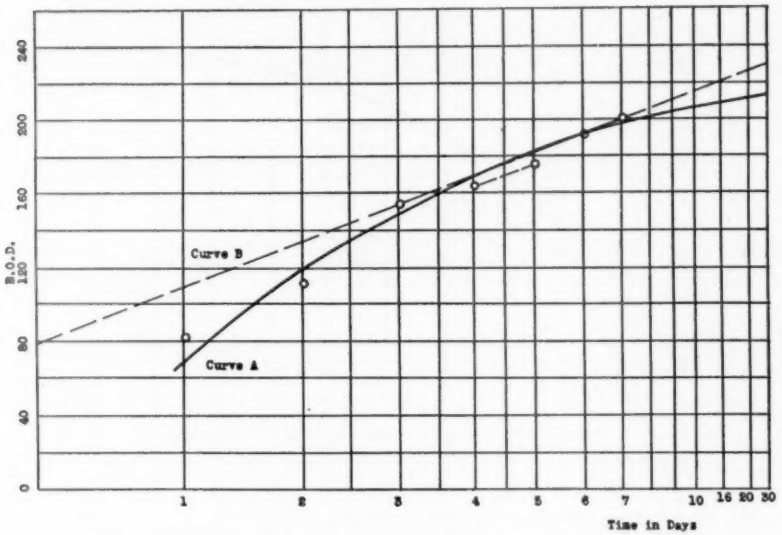

FIGURE 1.—Plot of observed B.O.D. on special paper with exponential time scale.

sample was not very well mixed prior to filling the small B.O.D. bottles for incubation.

Based upon the value of $L_a = 214$ from curve A, Figure 2, in which L is plotted against time, has been pre-

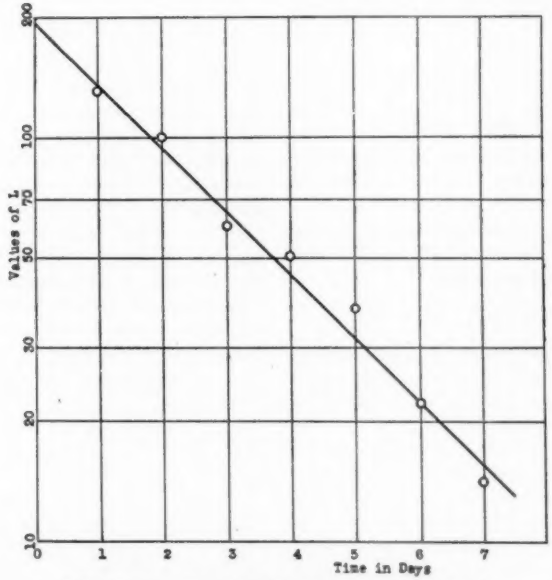

FIGURE 2.—Semilogarithmic plot used to find k.

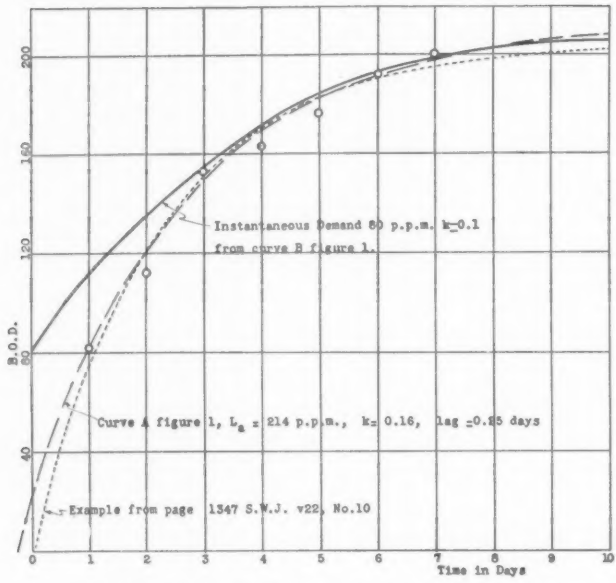
B.O.D.
Time in Days
Instantaneous Demand 80 p.p.m. k=0.1
from curve B figure 1.
Curve A figure 1, L_a = 214 p.p.m., k= 0.16, lag =0.25 days
Example from page 1347 S.W.J. v22, No.10

FIGURE 3.—Comparison of curve fitting methods.

pared. From the diagram it is apparent that the equation should be written

$$L = L_a\ 10^{-k(t-a)}$$

and from this $k = 0.16$ and $a = 0.25$ days. These results are not the same as those of the authors, principally as a result of using a different form of equation.

If the main interest is in L_a, curve A yields the result of 230, and $k = 0.1$ in the general equation

$$y = 80 + 150\ [1 - 10^{-0.1t}]$$

The same procedure applied to the data on page 1351 yields the expression

$$y = 20 + 190\ [1 - 10^{-0.1t}]$$

In conclusion it might be said that the general experience in the test work done in the Queen's University laboratory is that at 20° C. k has a value of 0.10 and that most of the higher values are a result of failing to recognize the effect of the initial demand for oxygen. Also, with only a limited number of results, which individually are subject to considerable error, it would seem that there is some merit in a method which is quick, if not so accurate mathematically.

Industrial Wastes

ASSIMILATION OF DAIRY WASTES BY ACTIVATED SLUDGE

By Sam R. Hoover, Lenore Jasewicz, Janet B. Pepinsky, and Nandor Porges

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Studies of the aerobic oxidation of a simulated dairy waste (0.10 per cent skim milk solids) in a continuous flow system showed that one-half the soluble solids was rapidly converted to cell substance and the remainder was oxidized completely to carbon dioxide and water (6). These results were obtained by determination of the amount and composition of milk waste introduced and of the resulting soluble products and insoluble cell residue. This paper reports a manometric study of the oxidation of skim milk and its major components, casein and lactose, by a mixed culture from an activated sludge plant successfully treating the waste from a small market milk plant.

Application of manometric methods in the study of waste disposal problems, especially the determination of B.O.D., has been proposed by various workers. Wooldridge and Standfast (14)(15)(16) made an excellent study of the effect of temperature, pH, and supersaturation of sludge with sewage on the rate of oxidation. These workers also established that carbon dioxide is the only gas produced in this oxidation; an essential condition for the use of the simple manometric procedures. Caldwell and Langelier (1) analyzed thoroughly the theory and practice of the various manometric techniques and proposed an adaptation of the Warburg apparatus in which the usual 15-ml. vessels are replaced by 125-ml. flasks. They recommend its use in routine determinations of B.O.D. of trade wastes and in sewage research studies. Dawson and Jenkins (3) recently reported an extensive study of oxygen requirements by activated sludge in which the effects of a number of variables were measured. These papers should be consulted by workers interested in the application of manometric methods to a broad range of sewage problems.

The techniques required in the study of bacterial and tissue respiration have been well worked out, and the standard Warburg apparatus is especially well suited for such research. These procedures have been applied just as they are described in standard published methods (4)(13).

Experimental

Six liters of activated sludge were placed in the 20-l. Humfeld aerator. This culture was developed to 20 l. by adding a solution containing 0.1 per cent skim milk solids at a rate of 1.1 l. per hr., and was maintained at that volume by feeding continuously at this rate and removing the effluent. The temperature was 30° C. Other details of the procedure have been described previously (6). Manometric experiments were initiated on the second day and completed within three weeks. A later series of experiments was conducted on sludge within an hour of the time it was obtained from the plant. Control experiments showed that the culture in the aerator retained its oxidative efficiency for several hours

without feeding and that the soluble nutrients were low. Therefore, the culture was not centrifuged and resuspended in the medium, but was used directly in the Warburg vessels with substrate added from the side arm. In about an hour, the time required to set up the experiment, the residual nutrients were almost completely oxidized. Oxygen demand was determined in the solutions by chemical oxygen demand determination. The chemical oxygen demand has been shown to be essentially equal to the 20-day B.O.D. on skim milk solids (11). In all experiments, nitrogen was supplied in excess as ammonium sulfate to compensate for its absence in lactose.

Figure 1 shows the rate and amount of oxidation of skim milk and of its two principal components in the approximate proportion in which they occur in skim milk. This experiment was performed on the second day after the culture was obtained. The similar rate and extent of oxidation of 0.50 mg. lactose per ml. of culture and 0.35 mg. of casein per ml. is a result obtained repeatedly. The culture without added nutrients had a low and practically constant endogenous respiration, oxidizing cell constituents for maintenance energy. The rate of oxidation in the vessels containing nutrients was high for a few hours, but dropped to almost the rate of the control in about 6 hr.

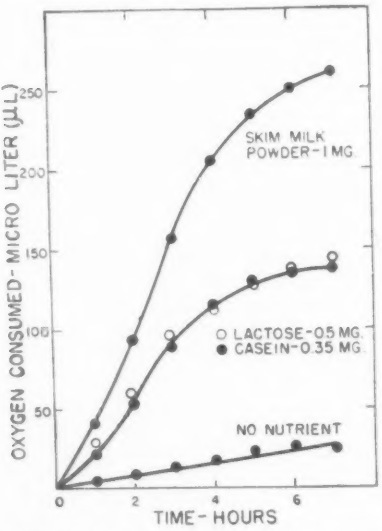

FIGURE 1.—Rate of oxidation of skim milk, lactose, and casein by 1.0 ml. of sludge cultured in fermentor for 2 days.

TABLE I.—Oxygen Utilization by Various Nutrients

Nutrient		Oxygen Utilization		
Type	Mg.	Theory (µL.)	Observed[1] (µL.)	%
Lactose	0.5	371	136	37
Casein	0.35	335	133	40
Skim milk powder	1.0	780	250	32

[1] 6 hours.

The percentage of the oxygen theoretically * required for complete oxidation was calculated from these data (Table I). Oxidation of only 32 to 40 per cent for the three substrates can be taken as indicating either partial oxidation or assimilation (growth of the cells). Because previous results showed there were negligible quantities of oxidizable substances left in the medium,

* Theoretical factors for complete oxidation of nutrients were calculated as follows:

Lactose:—Complete oxidation of one mole requires 12 moles O_2, or 1.06 g. O_2 per gram of lactose hydrate, 1.06 µg. O_2 = 0.742 µL. O_2. 0.5 mg. or 500 µg. = 371 µL. O_2.

Casein:—Analysis of this sample gave: C = 53.0 per cent; H = 7.0 per cent; N = 15.7 per cent; and O = 27.7 per cent. Complete combustion of carbon and hydrogen, assuming N is converted to NH_3, requires 1.48 g. O_2 per gram of casein, or 1.035 µL. O_2 per µg. casein. 350 µg. air dry casein (8 per cent moisture) = 335 µL. O_2.

Skim milk:—The sample used contained 36.3 per cent protein and 50.0 per cent lactose anhydride. The remainder is primarily ash and water. A calculation similar to the one above gives the value of 0.780 µL. O_2 per µg. air-dried skim milk. 1.0 mg. or 1,000 µg. = 780 µL. O_2.

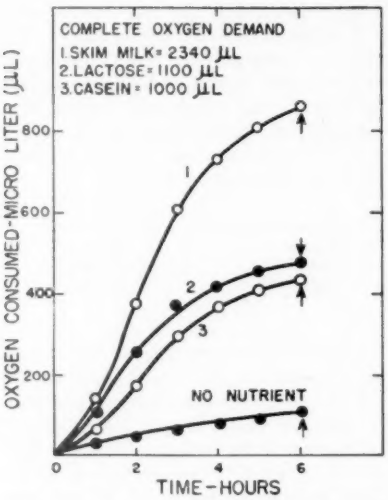

FIGURE 2.—Rate and extent of oxidation of skim milk, lactose, and casein by 3 ml. of sludge cultured in fermentor for 7 days. Arrows indicate when samples were taken and analyzed for residual substrate.

the second possibility was investigated.

A similar experiment (Figure 2) was therefore run in which the 1 ml. of culture per vessel was increased to 3 ml., with an accompanying 3-fold increase in added nutrients. After 6 hr., the measurements were stopped, and the contents of the vessel chilled and centrifuged cold. Residual substrate and/or partial oxidation products in the supernatant were determined by chromic acid oxidation (chemical oxygen demand) (11). The oxygen demand was 92 p.p.m. in vessel 1, 60 p.p.m. in vessel 2, 96 p.p.m. in vessel 3, and 72 p.p.m. in vessel 4. The culture put into the vessels originally contained 118 p.p.m. chemical oxygen demand. The added nutrients, therefore, had been completely removed from the solution. The calculated oxidation was 43 per cent for lactose and casein, and 37 per cent for skim milk, slightly higher than in the previous experiment. These results can only be interpreted as evidence of assimilation of the remaining 57 to 63 per cent of the protein and carbohydrate into cell tissue, an assimilation slightly higher than the 50 per cent obtained in the continuous flow experiments. The energy for this growth process was obtained from the portion of the substrate oxidized.

Respiratory quotient (R.Q. = CO_2/O_2) determinations made on the system further confirm the idea that the substrate is assimilated or oxidized completely. The results given in Table II are preliminary, but they correspond to a complete oxidation to CO_2 and water, with an R.Q. of slightly higher than 1.0 for lactose and skim milk and close to 1.0 for casein. The theoretical R.Q. for complete oxidation of lactose is 1.00; for casein it is 0.96 if the oxidation of carbon and hydrogen is complete and nitrogen is assumed to be produced as ammonia. The synthesis of cell tissue would be expected to have an R.Q. slightly greater than these

TABLE II.—Rate of Oxidation and Respiratory Quotient of Activated Sludge Culture Obtained May 31, 1950, and Maintained Aerobically in the Laboratory

Date	Oxidation Quotient (µL./mg./hr.)[1]				Respiratory Quotient (CO_2/O_2)[1]		
	None	Casein	Lactose	Skim Milk	Casein	Lactose	Skim Milk
6- 2-50	7	62	60	106	—	—	—
6- 7-50	18	84	96	168	—	—	—
6-20-50	—	116	90	183	1.00	1.03	1.03
6-21-50	—	—	114	—	—	1.06	—
6-22-50	—	111	96	—	1.00	1.03	—

[1] Values tabulated are the means of triplicates or of greater replication.

theoretical values, for the cell tissue which is synthesized has less oxygen in it than the substrates. The difference of about 0.05 is in agreement with this expectation.

The data on rate of oxidation are given in Table II as the oxidation quotient, which is the μL. O_2 consumed per mg. per hr. It is an absolute measure of the rate of oxidation of substrate by a culture.

The culture under aerobic conditions in the laboratory became more active, as the oxidation quotient shows. The relative rate of oxidation of lactose, protein, and skim milk remained essentially the same, despite the increase in activity of the culture. These results indicated that the culture studied in the laboratory was comparable in physiological properties to the activated sludge in the waste disposal plant. A specific experiment was run to confirm this indication. Fresh sludge was obtained from the plant, and the experiment was repeated on it. The results are given in Figure 3. It

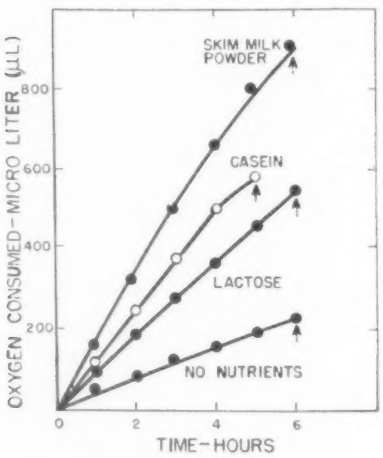

FIGURE 3.—Rate and extent of oxidation of skim milk, lactose, and casein by fresh sludge. Arrows indicate when samples were taken and analyzed for residual substrate.

can be seen that the two sets of data (Figures 2 and 3) are similar. The soluble portion of the fresh sludge contained 460 p.p.m. chemical oxygen demand. Therefore, the vessels containing no added nutrients had considerable available substrate. The oxidation quotient values were:

No added nutrients	12 μL./mg./hr.
Lactose	27 μL./mg./hr.
Casein	37 μL./mg./hr.
Skim milk	49 μL./mg./hr.

An analysis for residual chemical oxygen demand was performed after 6 hr., as indicated by the arrows in Figure 3. The lactose and casein had been completely removed and more than 90 per cent of the skim milk solids had been oxidized. The oxidation, therefore, accounted for about 50 per cent of the casein and lactose and 45 per cent of the skim milk solids. Conversely, assimilation of 50 and 55 per cent of the substrates into cell tissue is indicated.

The activated sludge contained a total chemical oxygen demand of 1,875 p.p.m., of which 1,415 p.p.m. were due to suspended cells. A chemical oxygen demand value can be converted to dry weight by use of the appropriate factor; for bacterial cells, an empirical factor of 1.25 g. O_2 per gram of dry weight was found. The sludge, therefore, contained 1,130 p.p.m. cells, a much higher value than that of about 400 to 500 p.p.m. maintained in the aerator by feeding 1,000 p.p.m. milk solids into it continuously. The data on rate of oxidation of skim milk solids on both a weight basis (oxidation quotient) and a volume basis (μL. per ml. culture per hr.), were plotted (Figure 4); the more recent results were used for the zero-day points and the data of Table II for the 2-, 7-, and 20-day points. Although there was almost a four-fold increase in the rate of oxidation on a weight basis, the culture maintained under the conditions of the experiment became more dilute, and

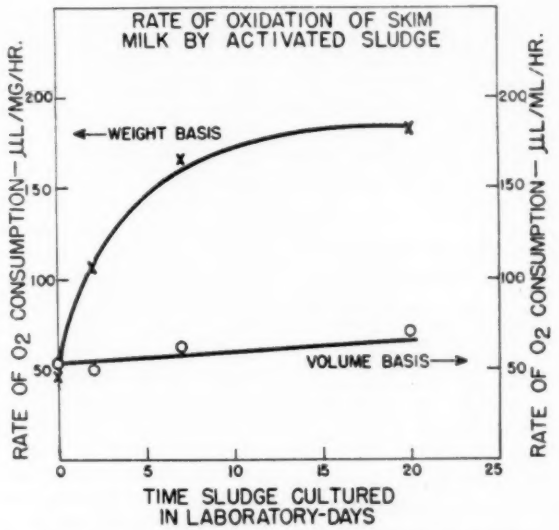

FIGURE 4.—Rate of oxidation of skim milk solids by activated sludge. Left ordinate calculated on weight of microbial cells present; right ordinate calculated on volume of culture present.

the activity per milliliter, or per cubic foot, remained essentially constant.

Discussion

The data presented in this paper are significant from two standpoints. First, the manometric determination of the amount of oxygen consumed, combined with the evidence from chemical oxygen demand determinations on the solution, proves that 60 per cent of the organic matter is assimilated into cell tissue and the remaining 40 per cent is burned to carbon dioxide and water to obtain energy for this assimilation. Second, they illustrate the type of information that can be obtained by manometric determinations in waste disposal studies. The absolute rate and extent of oxidation, the respiratory quotient, utilization of various oxidizable substances, requirements for nitrogen, potassium, and other elements, effects of pH and toxic compounds on the microorganisms, and other biochemical characteristics of the process can readily be measured. Further use of manometric methods in waste disposal studies is clearly indicated.

The efficiency of assimilation of about 60 per cent for the mixed culture studied is comparable with previous observations with bacteria and yeasts. The results are in general agreement with results of previous studies of the growth of *Rhizobium trifolii*, a symbiotic legume nodule bacterium, which grows readily on synthetic media if fixed nitrogen is supplied. An efficiency of 51.4 per cent was calculated from analysis of the respiratory quotient; determined values approached this value closely (5).

An oxidative assimilation of two-thirds of the carbon of carbohydrates and an oxidation of one-third to CO_2 has been observed in short-time experiments with various microorganisms. In 1946, Clifton (2) reviewed the subject of microbial assimilation.

Utilization of organic substrates by

activated sludge was the subject of an extensive study, which was summarized by Placak and Ruchhoft (10). B.O.D. and suspended solids determinations were used to study the assimilation of carbohydrates, proteins, organic acids, amino acids, and other materials by activated sludge in 24 hr., with the following results:

Class	Per Cent Oxidized		Per Cent Converted to Protoplasm (Organized Sludge)
	Range	Mean	
Carbohydrates	5 to 25	13	65 to 85
Alcohol	24 to 38	30	52 to 66
Amino acids	22 to 58	42	32 to 68
Organic acids	30 to 80	50	10 to 60

Peptone, which should be comparable with casein, was oxidized with an oxygen consumption of about 50 per cent of the theoretical value for complete oxidation; an accompanying increase in suspended solids accounted for the other 50 per cent. Assimilation of 80 per cent of the lactose fed is indicated. Their data on other carbohydrates indicate that a nonoxidative assimilation or true storage of carbohydrate occurred, because starch, for example, was removed from the solution without an increase in oxygen consumption. No nitrogen was supplied in these experiments, and it is probable that oxidative assimilation of the carbohydrates was prevented by lack of nitrogen.

In the present experiments, adequate nutrients were supplied for growth, and, consequently, growth or oxidative assimilation was the primary process. Otherwise the present results and those of the U. S. Public Health group (10) are in excellent agreement.

The present results are also in agreement with waste disposal studies of Jenkins and Wilkinson (7). When sufficient nitrogen was supplied, lactose was assimilated by activated sludge, with an increase in weight equal to 43 per cent of the added lactose. Lactose removal was rapid under these conditions. If nitrogen was limited, the rate of lactose removal was comparatively slow, but assimilation of the lactose produced an increase in sludge solids equivalent to 39 per cent of the added lactose.

In experimental aeration studies, Trebler (12) has repeatedly obtained B.O.D. reductions of about 50 per cent, and McKee (9) has recently reported a removal of 37 per cent in a dairy waste aeration plant utilizing no sludge separation or removal. The results of all these investigations of various types are consistent. They indicate a rapid assimilation of dairy waste by activated sludge; about 50 per cent of the waste is oxidized so that the remaining 50 per cent can be assimilated into cell tissue.

The rate of this oxidation is of great importance in plant practice. Johnson (8), for example, reported a complete absence of dissolved oxygen during the period when dairy waste containing 500 to 1,000 p.p.m. B.O.D. was being fed rapidly into an aeration tank. Any continued period of anaerobic conditions can be expected to result in acid production, with a consequent fall in pH and lessened activity of the sludge. This situation would be especially serious in a municipal sewage plant designed for the more dilute domestic waste.

Summary

The rate and extent of oxidation of skim milk, casein, and lactose by activated sludge were determined by manometric and chemical analysis. Activated sludge was successfully cultured in the laboratory without alteration of its physiological characteristics. Skim milk at a concentration of 1,000 p.p.m. was completely removed from the solution in 6 hr.; 60 per cent was assimilated into cell tissue and 40 per cent was oxidized completely to carbon di-

oxide and water. Casein and lactose were converted into cell tissue in a similar manner, but at a slightly lower rate. The results are compared with the results of previous studies of bacterial growth processes and of the metabolism of activated sludge.

Acknowledgment

The material herein is a report of a study, made under the Research and Marketing Act of 1946, presented at the meeting of the American Chemical Society held at Chicago, Ill., in September, 1950.

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CHEMISTRY OF WASTE CYANIDE TREATMENT *

By David Milne

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Many manufacturing organizations in the metal processing field are faced with the necessity for installation of waste treatment procedures for the various harmful wastes lost from their operations. To most of these firms the solution of their problems will lie in the selection of some method now available and in operation for the treatment of the particular waste with which they are concerned. To some operations, however, the known methods of treatment have disadvantages from any of several standpoints which would make their use burdensome and costly. These firms, naturally, are reluctant to spend money on treatment procedures which may prove to be inadequate in the future, and progress in the control of the industrial waste problem is slowed by hesitancy in accepting the known methods. The feeling always exists that some better and more economical treatment process may be discovered in the near future, especially under the pressure of investigation now proceeding, and that the wiser course would be to await the development of newer methods.

This suspicion exists in the field of cyanide treatment, where the chlorination procedure seems to have the greatest following. The obvious objections to chlorination from the operating standpoint (high cost for chemicals, high equipment maintenance, hazard, etc.) have caused some speculation on the possibility of developing simpler and better methods for destruction of this waste. In addition to the obvious steps of better process control and recovery of cyanide solutions, certain chemical and physical procedures have been suggested as a means to this end. It is the purpose of this paper to review the chemistry of these treatment methods.

Because these treatment processes involve certain fundamental chemical reactions, and because each basic reaction equilibrium provides a wide choice of similar reactions, the subject may be handled best by setting up three objectives for discussion:

1. Classify the reactions in which cyanides may be involved under their particular equilibrium systems.
2. Classify the available treatment methods under the appropriate equilibrium system for each.
3. Review each equilibrium system for other reactions of possible use as treatment methods for cyanides.

A review of the sources and character of waste waters from cyanide processes might be of some use as a general background to the reactions involved in their treatment. In metal working processes cyanides are wasted from plating operations, heat treatment, or neutralizing dips involving the use of sodium cyanide. The waste waters are never simple solutions of sodium cyanide in water, but contain many other chemicals which may or may not modify the effect of some subsequent treatment agent. In solutions discharging from plating systems, for instance, the effluent may contain any of several heavy metal cyanide complexes, free sodium hydroxide, and various organic brighteners and surface active agents

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in addition to the free sodium cyanide. In heat treatment wastes ions of sodium, potassium, and barium may be present, together with carbonates, borates, chlorides, cyanates, or other complicating materials. Metallic complexes may be found again in discharges from cyanide neutralizing dips, together with sulfates or other acid radicals from the acid solution preceding the dip.

In addition to the chemical agents lost from the process, the composition of the water itself may affect the equilibrium of the system. In some cases the waste material intended for treatment is present to the extent of only a few parts per million, and the raw water being used may have many times that much dissolved matter present (Table I). It can be appreciated quite readily that certain of these dissolved materials may exert a considerable effect on treatment agents in competition with the material to be treated.

The concentration of cyanide in metal processing wastes is extremely variable, and depends on several factors. Included among these are rate of rinse-water flow, drainage time allowed parts between process tanks, work load, original solution composition, and the shape of the part being processed. As an example of the amount of cyanide the treatment plant may be called on to handle continuously, the rinse waters from one large zinc-plating plant carry an average of 7.78 lb. of cyanide (as CN) per hour. In another plant applying copper, nickel, and chromium, the cyanide load from rinse waters averages 0.90 lb. cyanide (as CN) per hour. It is possible, of course, that conservation measures might reduce these loads to the treatment plant and effect some material saving.

As with most other industrial waste problem solutions, the methods available for disposal and treatment of cyanides may be classified under two general headings as follows:

1. Physical methods:
   a) Dilution.
   b) Ponding.
   c) Aeration.
   d) Evaporation.
   e) Ion exchange.
   f) Electrolytic oxidation.
2. Chemical methods:
   a) Neutralization.
   b) Complexation.
   c) Precipitation.
   d) Oxidation-reduction.
   e) Addition.

Obviously, some of the activity indicated under "Chemical methods" may

TABLE I.—Comparative Water Analyses

	Trenton, N. J.	Detroit, Mich.	Dayton, Ohio	River Rouge, Mich.
Source of supply	City	City	City	Well
Calcium, Ca (p.p.m.)	17	27	90	480
Magnesium, Mg. (p.p.m.)	5	7	35	48
Sodium, Na (p.p.m.)[1]	7	3	7	350
Bicarbonate, HCO_3 (p.p.m.)	47	92	339	422
Sulfate, SO_4 (p.p.m.)	30	19	83	1,780
Chloride, Cl (p.p.m.)	5	6	10	1
Nitrate, NO_3 (p.p.m.)	1	—	13	—
Silica, SiO_2 (p.p.m.)	6	3	10	18
Total diss. solids (p.p.m.)	100	119	416	2,900[1]
Total hardness, $CaCO_3$ (p.p.m.)	67	97	368	1,400
pH	7.4	7.4	—	6.7
Hydrogen sulfide	—	—	—	Strong
Hardness (gr. per gal.)	3.9	5.7	24.2	82

[1] Calculated.

also be in effect during the operations listed under "Physical methods." As the scope of this paper is confined to the chemical methods of treatment, no further attention is given to the physical methods.

Neutralization

The methods for disposal of cyanide making use of neutralization or acidification have been discussed extensively elsewhere, and will only be touched on briefly in this discussion. The neutralization methods include the release of hydrocyanic acid by use of acid solutions or by acid gases. Acid solution methods normally make use of low cost sulfuric acid or waste acids from processing to release gaseous HCN, which is then removed from the solution by aeration and discharged to the atmosphere, usually through a high stack. Considerable dilution with air is normally given to this gas to insure an effluent gas mixture of low toxicity.

$$2NaCN + H_2SO_4 = 2HCN \uparrow + Na_2SO_4$$

The methods making use of acid gases include the use of flue gas from powerhouse stacks, or sulfur dioxide, either from sulfur burners or by-product SO_2. In this case, the cyanide is again released as free hydrocyanic acid and is removed from the solution by the passage of the waste gases. The reactions accompanying this form of treatment will vary considerably with the conditions present, but may proceed in general as follows:

With sulfur dioxide:

$$NaCN + SO_2 + H_2O = HCN \uparrow + NaHSO_3$$

$$2NaCN + 2SO_2 + O_2 + 2H_2O = 2HCN \uparrow + 2NaHSO_4$$

With carbon dioxide:

$$NaCN + CO_2 + H_2O = HCN \uparrow + NaHCO_3$$

A second method of neutralization is that in which raw water is used to dilute the cyanide-containing effluent. As the original cyanide solution is relatively high in free alkalinity, the addition of water containing large quantities of bicarbonate would tend to form a buffer system in which the pH value is maintained in the neighborhood of 7.

$$NaOH + NaHCO_3 = Na_2CO_3 + H_2O$$
$$Na_2CO_3 + CO_2 + H_2O = 2NaHCO_3$$

Under these conditions the sodium cyanide present becomes hydrolyzed to form free hydrocyanic acid and sodium hydroxide. The sodium hydroxide in turn is again reacted upon by free sodium bicarbonate and excess carbon dioxide from the atmosphere to add to the buffer capacity of the system. This results in gradually increasing concentrations of free hydrocyanic acid as the system approaches the neutral pH zone. The ratio of free hydrocyanic acid to cyanide ion is then dependent on the ionization constant of hydrocyanic acid, and the concentration of hydrogen ion present in the system, as follows:

$$HCN = CN^- + H^+$$

$$\frac{[HCN]}{[CN^-]} = \frac{[H^+]}{Ka}$$

This mechanism has been described previously (1).

A further possibility in neutralization methods is the apparent formation of ammonium formate and azulmic acid from hydrolysis of the hydrocyanic acid by water.

$$HCN + 2HOH = H{-}C(=O){-}ONH_4 + \text{azulmic acid}$$

It has been found (2) that calcium and magnesium salts promote this hydrolysis, and because these ions are present in most hard natural waters, it is conceivable that some relationship would exist between the hardness of water and the rate of hydrolysis of

the free hydrocyanic acid released by the buffer action described above.

Complexation

One of the most familiar properties of the cyanide ion is its ability to form very tightly bound complexes with certain metals. The stability of these complexes varies with the metal used, and depending on this metal the complex can be either very greatly dissociated in water or may be very slightly dissociated. One of the most familiar cyanide complexes is that in which iron is bound with the cyanide to form the ferrocyanide and ferricyanide complexes. These complexes are exceedingly stable and unless heated do not break down into the iron salt and free hydrocyanic acid in the presence of strong mineral acid. Strong oxidation of the ferrocyanide simply results in formation of the ferricyanide rather than oxidation of the cyanide portion of the molecule to cyanate. Several investigators have proposed the use of ferrocyanides as a means for complexing the cyanide ion into a less toxic material; the process has been attempted in England for some time with fair results.

$$Fe^{++} + OH^- = Fe(OH)_2$$

$$Fe(OH)_2 + CN^- = [Fe(CN)_6]^{=} + 2OH^-$$

Inspection of the above equilibria gives some clue as to the reason for the poor results obtained by this method in some instances. As the reaction proceeds a certain quantity of hydroxyl ion is formed, together with the ferrocyanide. As this is a system in equilibrium, any increase in the hydroxyl ion concentration will tend to displace the equilibrium to the left with the consequent formation of cyanide ion. This situation will frequently exist in treatment systems of this type due to the necessity for first forming the ferrous hydroxide reagent. Unless steps are taken to remove hydroxyl ion as rapidly as it is formed the method cannot be expected to produce complete elimination of cyanide. Therefore, if this method is to be used, some optimum pH value must be found at which the equilibrium between the ferrous ion-cyanide and ferrocyanide-hydroxide system is to the best advantage of the treatment process. Another disadvantage lies in the fact that oxidation of ferrous ion in the system leads to the formation of the deep blue ferric ferrocyanide, or Prussian blue.

$$[Fe(CN)_6]^{=} + 2Fe^{++} = \underline{Fe_2[Fe(CN)_6]}$$

$$\underline{Fe_2[Fe(CN)_6]} + [O_2] = \underline{Fe_4[Fe(CN)_6]_3}$$

The appearance of this highly colored precipitate in a watercourse would be considered detrimental.

Some attention has been given recently to the complexation of cyanides with other metals in an attempt to find some more simple disposal method for these materials. In surveying the available metals from plating operations it was found that nickel salts held the most promise as a treatment agent for cyanides. In the use of nickel salts the same general chemistry is evident as is found in the formation of complexes with other metals. As the nickel ion is added to a cyanide solution there is formed an equivalent amount of nickel cyanide, which immediately dissolves in the free cyanide present to form the nickel cyanide complex. As the addition of nickel is continued, more nickel cyanide complex is formed until no free cyanide remains. At this point, the addition of an excess of nickel ion will result in the precipitation of nickel cyanide as a highly insoluble precipitate.

$$2Ni^{++} + 4CN^- = \underline{Ni_2(CN)_4}$$

$$\underline{Ni_2(CN)_4} + 4CN^- = 2[Ni(CN)_4]^{=}$$

In the use of nickel as a complexing agent for cyanides the formation of this precipitate can be considered to indicate the absence of free cyanide. In the normal process making use of this complex the solution being treated would be required to pass through a

sludge bed of previously precipitated nickel cyanide or other nickel precipitates, which would react immediately with any excess free cyanide remaining in the treated rinse water. Investigation of the use of nickel ion in this manner indicates that from a solution containing originally 100 p.p.m. CN only 0.34 p.p.m. CN would be made available by dissociation of nickel complex. This concentration is low enough so that no damage would result to fish life, and, in fact, some experiments have been conducted indicating that fish would survive in a solution of this concentration containing nickel cyanide complex. The possibility of using nickel as a complexing agent in cyanide waste treatment has been discussed in detail elsewhere (3).

Precipitation

Some thought has been given to the possibility of recovering cyanides as metallic cyanide precipitates by addition of heavy metal salts. The thinking behind this treatment is that a cyanide precipitated as a metallic salt may then be re-used in a plating bath of that metal and will result in lowered cost for plating chemicals. The mechanism of the precipitation process with these heavy metals is essentially that described under "Complexation," and, in effect, is simply the result of saturation of the complex cyanide with the metal salt. The obvious difficulty in this method of treatment is in the possibility of adding an excess of a toxic metal salt, which could produce as much damage as the cyanide, if not more, during subsequent disposal operations. In other words, an additional treatment clean-up would have to be given to make sure that no metallic salts would escape with the treated effluent.

Calculation of the concentrations of cyanide available from these precipitation processes is encouraging, but appears to be inaccurate. It can be calculated, for instance, by means of the solubility data for zinc cyanide and the dissociation constant for the zinc cyanide complex, that the amount of free cyanide available from solubility of zinc cyanide in water should be approximately 1.6 p.p.m. CN. From information published, however, it is indicated that from 5 to 8 p.p.m. of cyanide are found in this system (4). This would indicate that the precipitate is not entirely zinc cyanide, but is probably a hydrated or basic zinc cyanide salt. This basic zinc cyanide is apparently unstable in water solution and hydrolyzes to form zinc hydroxide and free HCN.

Oxidation-Reduction

The most obvious and highly publicized oxidation-reduction method for cyanide is that making use of alkaline chlorination. This process has been discussed thoroughly in the literature and will not be dwelt upon. The essential equations describing the reactions involved with sodium cyanide are:

$$NaCN + 2NaOH + Cl_2 = NaCNO + 2NaCl + H_2O$$

$$2NaCNO + 4NaOH + 3Cl_2 = 6NaCl + 2CO_2 + N_2 + 2H_2O$$

The presence of metal cyanide complexes appears to complicate these reactions in some way, and considerably more investigation is needed on this phase of the problem.

Some attention has been given to the possibility of using potassium permanganate as an oxidizing agent for cyanides. In this reaction the permanganate was reduced to dioxide, as might be expected in alkaline solution, and the cyanide oxidized to cyanate.

$$MnO_4^- + 3CN^- + H_2O = 2\underline{MnO_2} + 3CNO^- + 2OH^-$$

This reaction was, however, uncertain

and formation of the dark brown manganese dioxide sludge made it undesirable as a treatment method unless recovery of the sludge was practiced.

Some attempts have been made to use sodium thiosulfate as an oxidizing agent for cyanides. In this reaction sodium thiocyanate is obtained as the final product, together with some free sulfur. The sodium thiocyanate, although considerably less toxic than cyanide, has, nevertheless, some degree of toxicity and must be diluted considerably before disposal.

An intriguing possibility in the oxidation of cyanides is the reaction between chromate and cyanide which would take place in alkaline solution as follows:

$$3CN^- + 2CrO_4^= + H_2O = 2OH^- + 2CrO_2^- + 3CNO^-$$

The usual methods of calculation involving the use of oxidation potentials and derivation of the free energy expression indicate that this reaction is theoretically possible. Theoretical possibility, however, is no indication of practical possibility, as no mention is made of the time element involved. The experience of this organization has been that this reaction does not take place within reasonable time limits for satisfactory disposal methods. In view of the fact that the reaction is possible, it may also be possible to find some catalytic agent that will accelerate this reaction rate, making it possible to use the waste chromate from chrome plating as a treatment agent for the cyanides. If this catalyst can be found and is economically usable, then the electroplater will be provided with an excellent and automatic method for disposal of two of his most troublesome wastes. The chromate would be reduced to the non-toxic and harmless chromic state and the cyanide oxidized at the same time to the relatively harmless cyanate. Naturally, in any plant operation an excess of one or the other will be evident. This would mean that close technical supervision would be necessary to prevent harmful discharges of one of these materials.

An additional possibility in oxidation of cyanides, and one which has been generally overlooked in the field, is the utilization of rinse water from the copper-ammonia type plating bath. The copper-ammonia complex will react with cyanide under some conditions to form insoluble cuprous cyanide and sodium or ammonium cyanate.

$$2Cu(NH_3)_4^{++} + 3CN^- + 2OH^- = 2\underline{CuCN} + CNO^- + 8NH_3 + H_2O$$

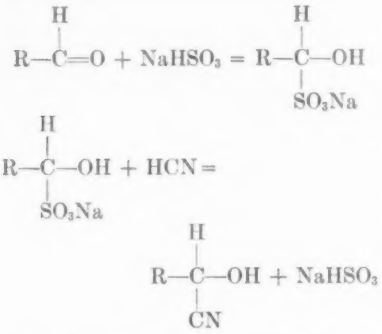
The reaction conditions under which this oxidation takes place have not yet been fully established.

Some organizations have made use of lime-sulfur mixtures to convert cyanides to thiocyanates. Although this reaction has been practiced at several places, it is not considered entirely reliable and the thiocyanate resulting from the reaction is still relatively toxic. The reaction is, therefore, only usable in certain non-critical locations and has definite drawbacks for general use.

Addition Products

One of the more obscure reactions of the cyanides is the ability of the cyanide to form an addition product with an aldehyde or a ketone. Usually this addition product is formed by reaction of the hydrocyanic acid with a bisulfite addition product of the aldehyde or ketone involved. The usual procedure in this case is to form the bisulfite addition product with any aldehyde or with a ketone which contains one methyl group. The addition product formed is then reacted with hydrocyanic acid to form a hydroxynitrile or a cyanhydrin. These materials precipitate from the solution or hydrolyze to form ammonia and various

organic hydroxy compounds such as glycolic acid.



The aldehyde addition products are generally of academic interest only, due to the expense involved for organic reagents and for the various reactions and manipulations through which the system must be taken.

Summary

As can be seen from the foregoing, the field of cyanide disposal by chemical means can be broken down rather easily into five main headings. Within each of these groups several reagents are available for the destruction of cyanides and investigations are indicated as being necessary on some of the materials proposed.

In general, the solution of chemical problems in the industrial waste field will come only as a result of knowledge of the fundamental chemistry and physics of the waste material. This is particularly true in the metal processing field, where the waste solutions may not be too complex in character, and where they may to some extent be identified as concentrations of definite chemical entities or physical states. Success in treatment of wastes will certainly not come as a result of hit or miss treatment methods, established on the often mistaken assumption that one waste is similar to another; neither will it come by application of black magic or "snake oil" treatments. Application of sound chemical principles based on complete knowledge of the fundamental chemistry involved is the only answer to the treatment problem.

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TO STUDY HEALTH HAZARDS OF TRACE CONSTITUENTS

Probing into a field largely unexplored, the Ohio River Valley Water Sanitation Commission will promote investigations to determine if unsuspected public health hazards exist as a result of trace constituents from industrial and other wastes that find their way into streams. An initial allotment of $13,500 was recently approved by the Commission for this work.

The Commission seeks complete information about the possible injurious nature of water supplies containing minute quantities of certain wastes.

Industries are to have an opportunity to participate in the program, inasmuch as the findings would have an important bearing on future control regulations covering disposal of wastes.

WASTE DISPOSAL AT A SYNTHETIC RUBBER PLANT *

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The synthetic rubber industry and its waste disposal problems are relatively new to this continent. The waste problems differ considerably for different plant sites, depending on the raw materials used and the number of intermediates produced. This paper deals with waste disposal at the plant of Polymer Corporation Limited, Sarnia, Ont.

The Polymer plant, located a few miles south of Sarnia on the St. Clair River, was built by the Dominion Government during World War II for the manufacture of synthetic rubbers. Construction and total operation were accomplished between June, 1942, and March, 1944. Since the war, production of rubber has been maintained, with approximately 30 specialized rubber types. In addition, the manufacture of chemicals, steam, electric power, and process water for other consumers has been undertaken.

The Process and Its Wastes

Using a mixture of light petroleum hydrocarbons, benzene, and isoprene as constituent raw materials, the Polymer plant integrates in a single project the production of butadiene, styrene, and isobutylene monomers and the various types of general purpose, specialty, and butyl rubbers produced from these monomers.

Table I is a list of the process units showing their functions, raw and accessory materials, products, and wastes.

The total process is composed of a series of continuous unit operations and unit processes subgrouped into the process units. In addition to the process units there are control and research laboratories, two pilot plants, a maintenance shop, an instrument shop, the storehouse, and the administration offices. Following are brief descriptions of the basic unit operations and unit processes, which are combined to make up the total process.

The steam and power plant, using pulverized coal as fuel, supplies process steam, electric power, and service water to the other units of the plant. The boiler feedwater is lime-soda softened and treated internally with phosphate. The wastes of the power plant are softener and boiler blowdown, flue gas, fly ash, and sluice ash.

Fractional distillation, carried out in towers similar to those of an oil refinery, is the commonest unit operation employed in the plant. It is used in all the process units for separation of hydrocarbon mixtures. Compression, refrigeration, and heat exchange with cooling water are used as auxiliary operations. Greatest use of fractional distillation is made in the light ends recovery unit. The wastes associated with fractional distillation, are hydrocarbon blowdown and blowoff of safety valves and small amounts of lubricating oils from pumps and compressors.

Countercurrent washing and extraction are other related and common unit operations used in the plant. In some locations hydrocarbon gas streams are washed with water or dilute caustic solution to remove traces of soluble impurities, the wash stream constituting

* Presented at 1950 Annual Meeting, Canadian Institute on Sewage and Sanitation; Lake of Bays, Ontario; Sept. 11–13, 1950.

TABLE I.—Functions, Products, and Wastes of Synthetic Rubber Process Units

Process Unit	Function	Raw and Accessory Materials	Products	Wastes
1. Steam and power	Provide service water, process steam, and electrical power.	Coal, fuel oil, fuel gas, water, lime, soda, phosphate.	Service water, steam, electrical power.	Sluice ash, fly ash, stack gases, softener sludge, boiler sludge.
2. Light ends recovery	Purify hydrocarbon feed, fractionate hydrocarbon mixture, and crack ethane to ethylene.	Hydrocarbon mixture (methane to hexane plus unsaturated homologues) caustic soda, diethanolamine.	Fuel gas, ethylene, propane-propylene cut, butane-butylene cut, pentane and heavier cut.	Hydrogen sulfides, mercaptans, spent caustic, light hydrocarbons, oils.
3. Isobutylene extraction	Extract and purify isobutylene.	Butane-butylene cut, sulfuric acid, caustic soda.	Isobutylene, spent C_4.	Sulfuric acid, C_4 hydrocarbon, caustic soda.
4. Butylene concentration	Separate and purify n-butylene.	Butane-butylene cut, acetone, caustic soda.	n-butylene, butane.	Acetone, oils, C_4 hydrocarbon, caustic soda.
5. Butylene dehydrogenation	Dehydrogenation of butylene to butadiene.	n-butylene, steam, fuel oil, fuel gas, quench oil.	Butadiene-rich hydrocarbon mixture.	C_4 hydrocarbon, oils, stack gas.
6. Butadiene extraction	Extract and purify butadiene.	Butadiene-rich hydrocarbon mixture, cuprous ammonium acetate solution, flux oil.	Butadiene, spent C_4.	C_4 hydrocarbon, cuprous ammonium acetate solution, oils.
7. Ethylbenzene	Alkylation of benzene and purification of ethylbenzene.	Ethylene, benzene, catalyst, caustic soda.	Ethylbenzene.	Fuel oil, tar, hydrochloric acid, caustic soda.
8. Styrene cracking	Dehydrogenation of ethylbenzene to styrene.	Ethylbenzene, catalyst.	Crude styrene, fuel gas.	
9. Styrene finishing	Purification of styrene.	Crude styrene, sulfur.	Styrene.	Heavy tar.
10. Butyl rubber	Polymerization and finishing of butyl rubber.	Methyl chloride, catalyst, ethylene, fuel gas.	Butyl rubber.	Scrap butyl, oil, light hydrocarbons.
11. Copolymer	Polymerization and finishing of general purpose and specialty rubbers.	Butadiene, styrene, brine, sulfuric acid.	General purpose and specialty rubbers.	Butadiene, styrene serum, softener sludge.

the waste. In the light ends recovery unit, both diethanolamine and caustic soda are used to extract hydrogen sulfide and mercaptans from the hydrocarbon feed to the plant. The solvents are regenerated by heating to drive off hydrogen sulfide and mercaptans as waste gases. The solvents become wastes only in cases of leaks or spills or when the caustic soda cannot be regenerated due to build-up of sodium hydrogen sulfide. In the isobutylene extraction unit and the butadiene extraction unit, strong sulfuric acid and cuprous ammonium acetate solution, respectively, are contacted with liquid hydrocarbon streams for the extractions. These solvents are recycled and become wastes only in cases of leaks or spills. Here again, hydrocarbon blowdown and blowoff of safety valves constitute the waste.

Cracking and dehydrogenation are related unit processes used in the light ends recovery unit for converting ethane to ethylene, in the butadiene dehydrogenation units for converting butylene to butadiene, and in the styrene cracking unit for converting ethylbenzene to styrene. The process consists of exposing hydrocarbon mixtures to a high temperature with or without the use of steam and/or a catalyst. The wastes associated with cracking and dehydrogenation are hydrocarbon blowdown and blowoff of safety valves, stable oil-in-water emulsions, stack gases, and spent catalyst or its breakdown products.

Polymerization is the chief unit process used in the two rubber units. In the butyl rubber unit, isobutylene, isoprene, and a catalyst are reacted in liquid methyl choride solution at − 150° F. to produce butyl rubber. The crumbs of rubber are first wet, then

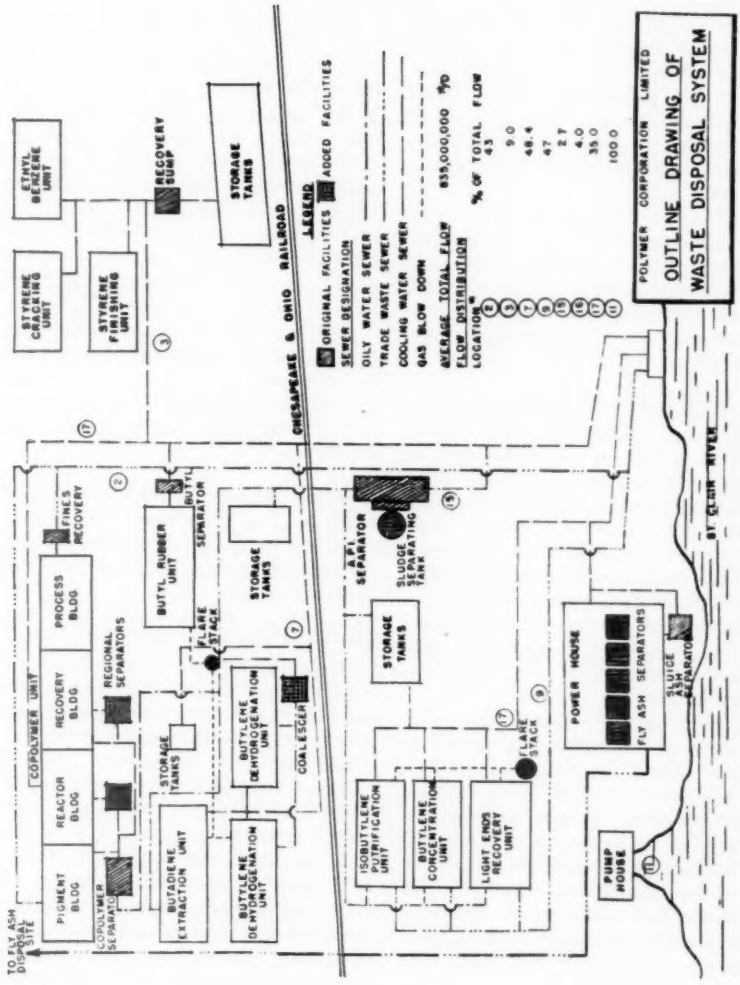

FIGURE 1.—Schematic diagram of synthetic rubber plant wastes disposal system.

screened, dried, milled into a sheet, and cut into lengths for packaging. In the copolymer rubber unit, butadiene, styrene, and other monomers are reacted as an emulsion in aqueous soap solution to form a rubber latex. The latex is coagulated, then the coagulum in turn is filtered from the serum, washed, dried, and compressed into blocks for packaging. The wastes from these two processes consist of waste rubber in various forms, styrene emulsion, and acidified brine-serum mixture.

Alkylation of benzene is carried out by contacting a mixture of ethylene and benzene with a catalyst. The product is a crude solution of ethylbenzene. Wastes from this process are hydrochloric acid, caustic soda solution, tar, and safety valve blowoff.

The Waste Problem

The waste problem has two aspects —the immediate one of installing and operating facilities to prevent river and atmospheric contamination and the longer term one of continual effort to reduce losses, re-use, or to recover and develop useful outlets for wastes. In this latter aspect all wastes may be considered temporary, as they represent either valuable intermediate and accessory materials or potentially useful materials.

At Polymer, the potential river contaminants are discharged to the waste disposal system in about 4 per cent (3.4 m.g.d.) of the total service water, the other 81.6 m.g.d. being used as cooling water. As indicated in the previous section, the origins of the wastes are widely distributed and the types at the origins are fourfold; namely, organic, suspended and dissolved, plus inorganic, suspended and dissolved. Organic suspended wastes include emulsified and free oils and particles of rubber from colloid size to fairly large chunks. Organic dissolved wastes include acetone and traces of dissolved oils. Inorganic suspended wastes include boiler and softener blowdowns and sluice ash. Inorganic dissolved wastes include caustic soda, sodium hydrogen sulfide, sulfuric acid, cuprous ammonium acetate, brine, hydrochloric acid, and aluminum chloride.

The potential atmospheric contaminants also have widely distributed origins and may be classified conveniently as follows: odorous and corrosive gases, highly inflammable gases, and fly ash. The odorous and corrosive gases include stack gases, hydrogen sulfide, vaporized mercaptans, and hydrogen chloride. The highly inflammable gases include safety valve blowoffs of light hydrocarbons plus periodic blowoffs due to upsets or shutdowns. Fly ash is found in the power plant stack gas.

Another class of wastes are those bulk quantities of materials which must be disposed of periodically. These include scrap rubber, spent catalysts, tars, sludge from brine softening, and garbage.

Original Design of Disposal System

Figure 1 is a schematic diagram of the waste disposal system, the original facilities being indicated with plain hatching.

Potential River Contaminants

The original design provided for a subdivision of used water disposal via an oily-water sewer, a trade waste sewer, and a cooling-water sewer.

The oily-water sewer was built to carry oil-bearing waters. It was provided with two separators: one, an alternate overpass-underpass type at the copolymer unit for separation of rubber wastes for disposal; the other, an A.P.I. oil separator near the outlet of the sewer for removal and reclamation of slop oil. The outlet of the oily-water sewer was connected with one of the large cooling-water sewers for dilution of any wastes escaping the A.P.I. separator. All manholes on the oily-water sewers were vented through pipes extending 15 ft. above ground level to

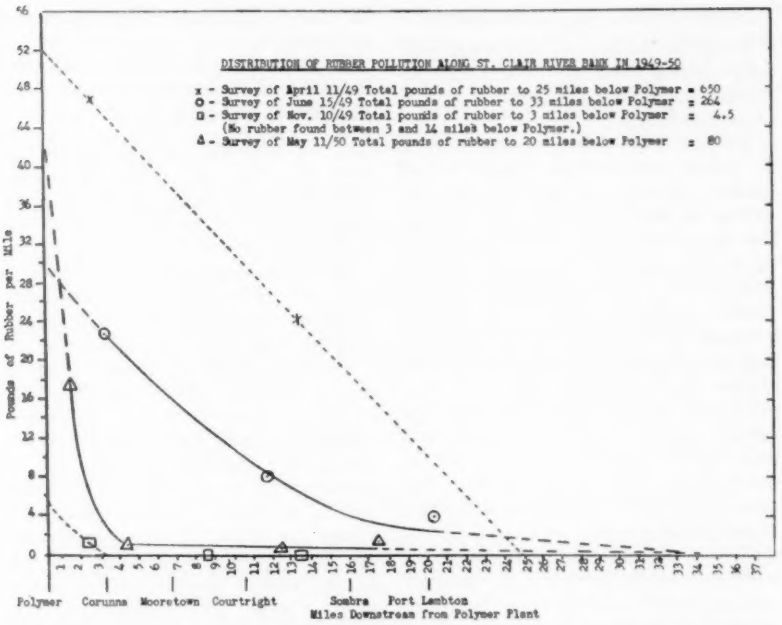
DISTRIBUTION OF RUBBER POLLUTION ALONG ST. CLAIR RIVER BANK IN 1949-50
x - Survey of April 11/49 Total pounds of rubber to 25 miles below Polymer = 650
O - Survey of June 15/49 Total pounds of rubber to 33 miles below Polymer = 264
□ - Survey of Nov. 10/49 Total pounds of rubber to 3 miles below Polymer = 4.5
(No rubber found between 3 and 14 miles below Polymer.)
Δ - Survey of May 11/50 Total pounds of rubber to 20 miles below Polymer = 80
Pounds of Rubber per Mile
Polymer
Corunna
Moorestown
Courtright
Sombra
Port Lambton
Miles Downstream from Polymer Plant

FIGURE 2.—Rubber pollution distribution surveys along St. Clair River bank in 1949–50.

provide for the harmless escape of volatile hydrocarbons.

The trade waste sewer was installed to carry soluble inorganic wastes, such as acids, alkalis, and brine. A separator in the fines recovery building at the copolymer unit was provided for separation of rubber prior to discharge of serum to the trade waste sewer.

Two cooling-water sewers were installed to carry the large volume of used cooling water and storm runoff. One of the cooling water sewers receives process water from the Butyl Unit after it has passed through a series of separating sumps, process and cooling water mixed from the Ethylbenzene and Styrene Units, and also the effluent of the oily water sewer below the A.P.I. separator. The other cooling-water sewer receives the overflow from a large pit, which was installed for the settling and disposal of the sluice ash from the steam and power plant. All sanitary facilities drain into regional septic tanks, the overflows from which pass to the cooling-water sewer.

Potential Atmospheric Contaminants

Two flare stacks 200 ft. high were installed and connected with safety valve blowoffs and blowdown facilities. One of them was also connected to receive hydrogen sulfide and vaporized mercaptans. These flare stacks were provided with pilot flames at their upper ends to assure continuous combustion of the gases. Five stacks were erected on top of the power house to provide for the emission of stack gases at a height of 185 ft.

Bulk Wastes

A dumping site was provided for the bulk wastes, the combustible constituents of which were to be burned periodically.

Improvements in Waste System

Facilities added to the waste disposal system since the original installation are indicated in Figure 1 with cross hatching.

The oily-water sewer was called upon to handle considerable quantities of rubber fines and styrene emulsion, as well as emulsified and free oil. During the early period the separators were used to accumulate the rubber wastes. The results were agglomeration and further polymerization of the wastes, by-passing, poor separating efficiency, and periodic major cleanouts requiring several days and much labor. A conical bottom sludge separating tank was erected at the A.P.I. separator and daily skimming of the oil-rubber-solids-water sludge from the separator to the tank was instituted. Weekly skimming of the primary section of the copolymer separator was adopted, using a pump with a movable suction. A coalescer and separator was installed at the butadiene dehydrogenation unit to break the oil-in-water emulsion and recover quench oil. Facilities were installed at the copolymer unit to permit further recovery of styrene from water and to coagulate styrene from water during periods of unavoidable loss. The net results of the changes outlined above were:

1. Improved average condition of the A.P.I. oil separator effluent—namely, a reduction of total organic content from 465 p.p.m. to 300 p.p.m. and oil content from 140 p.p.m. to 70 p.p.m.
2. Reduction of 50 per cent in oil loss to burning pit.
3. Reduction of 75 per cent in cleaning time and, therefore, down time of oil separator.
4. Reduction of 60 per cent in down time of copolymer separator.
5. Reduction of sewer and manhole fouling between the two separators.
6. Reduction of quench oil waste and breaking of the oil-in-water emulsion at the butadiene dehydrogenation coalescer.
7. Reduction of styrene waste and breaking of the styrene-in-water emulsion at the copolymer unit.

The oil separator effluent is diluted with 23 times its volume of cooling water several hundred yards before entering the river (where it enters the cooling-water sewer).

The trade waste sewer was receiving acids and alkalis in batch discharge. These have been largely put on a continuous basis and the quantities of acids and alkalis are roughly equivalent so that the pH of the effluent at the river ranges from 6 to 8. The atmospheric acid concentrator at the isobutylene purification unit was replaced with a vacuum concentrator, which decreased sulfuric acid discharge by 63 per cent and lengthened the period between changing the acid in the system from three months to three years. The separator in the fines recovery system at the copolymer unit is of the alternate overpass-underpass type and was originally covered. The cover has been removed and it is now skimmed frequently enough to keep the last two sections free of floating solids. The result is that the average suspended content of the separator effluent has decreased from 450 to 100 p.p.m. and only the finest material escapes.

Regular inspection and cleanout of all separators, sumps, and septic tanks has been instituted. In addition to the dilution that various wastes receive within the cooling-water sewer, all effluent streams are brought together at a common point at the river bank so that all waste-bearing streams get a dilution of about 1:24 with used cooling water. As a yardstick of the downstream rubber pollution and progress of the waste disposal program, periodic surveys have been made of the rubber pollution on the river bank to 20 miles

downstream. The results of these surveys are shown in Figure 2.

A fly ash removal system installed at the steam and power plant removes 85 per cent of the ash from the stack gases and carries it in water slurry 2.5 miles to a disposal site.

The disposal site for bulk wastes has been changed from a location near the river to 2.5 miles inland near the fly ash disposal site.

Conclusion

The amounts of contaminating materials in a plant of this type are not large, but their points of origin are widely scattered. In addition the methods of treatment required vary and it is necessary, generally, to give individual attention at the source rather than to use a common treating system. These facts were recognized in the original plant design. It has been possible, therefore, to bring about the considerable improvements described at a minimum cost. If a common collecting system only had been provided, much of the reduction of undesirable discharge would have been very difficult economically.

NUCLEAR REACTOR TECHNOLOGY SCHOOL

Industrial organizations interested in obtaining special training in nuclear reactor technology for experienced engineers in their employ are invited by the U. S. Atomic Energy Commission to sponsor their enrollment in the 1951–52 session of the Oak Ridge School of Reactor Technology. Application deadline is April 1, 1951, and the school term begins September 10, 1951.

Established in 1949 at the Oak Ridge National Laboratory, the school operates a 12-month session open to two categories of engineering candidates. A limited number of recent college graduates are accepted in category A in the status of student employes. Category B students are selected from the applications sponsored by government agencies and private industrial firms interested in participating in the AEC national nuclear energy program. Such firms need not be connected with the AEC currently.

Officials of the Oak Ridge Reactor School point out that the majority of problems encountered in the field of nuclear engineering involve the same fundamental engineering and management skills common to industry generally. This school offers an unparalleled opportunity for experienced engineers to obtain a thorough understanding of the specialized problems the AEC deals with in its nuclear engineering program. Trainees remain on the payrolls of their home organizations, and upon returning after completion of the course, can be expected to help strengthen their companies' position to participate in the national atomic energy program.

Further information and application forms may be obtained by writing to the Director, Oak Ridge School of Reactor Technology, P. O. Box P, Oak Ridge, Tennessee.

Because much of the material presented in the curriculum of the Oak Ridge School of Reactor Technology will be classified, all enrollments are contingent upon a personal security investigation. Announcements of appointments are expected to be made in April.

OBSERVATIONS ON THE REMOVAL OF RADIOACTIVE MATERIALS FROM WASTE SOLUTIONS

By Conrad P. Straub

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At Oak Ridge National Laboratory the responsibility for liquid radioactive waste disposal has been delegated to two divisions of the Laboratory: the Chemical Technology Division and the Health Physics Division—through the latter to its Radioactive Waste Disposal Research and Development Section. The Chemical Technology Division is responsible for the control of the wastes at their source, and for the treatment of wastes resulting from chemical processing and from the separation of reactor-produced radioactive isotopes. Thus, it is concerned primarily with the treatment of relatively small volumes of concentrated and highly radioactive materials. To the Radioactive Waste Disposal Research and Development Section is assigned the responsibility of developing techniques for treating the residual radioactive wastes. Before discharge into waters beyond the controlled area of operation is permitted, the wastes must meet limits of radioactive concentration prescribed by the Health Physics Division. For example, the maximum permissible tolerance concentration of mixed fission products in water has been set at 10^{-7} microcuries per cubic centimeter. Limits have been established also for certain specific radioactive isotopes.

As sanitary engineers and sanitary chemists have been and are engaged in the treatment of large volumes of domestic and industrial wastes containing low concentrations of foreign matter, the Radioactive Waste Disposal Research and Development Section is following the sanitary engineering approach in developing techniques for the treatment of the residual radioactive wastes.

An element is radioactive when the nuclei of the individual atoms are unstable. The radioactive disintegration of an unstable atom results in the production of alpha and beta particles and gamma rays, or some combination of these activities. Inasmuch as the chemical properties of a particular element are not contingent upon the stability of the nucleus, both ordinary and radioactive forms of an element will undergo the same chemical reactions. Many operations with radioactive materials are carried out using trace quantities of the reacting substances and these reactions do not always follow the same course observed when macro concentrations of the elements are reacted. As a result of this factor, a radiochemical reaction may not always follow the known stoichiometric reaction and difficulties may arise. In the examples given later, however, it will be noted that the techniques that apply to the treatment of chemical wastes usually also apply to the treatment of radioactive chemical wastes.

Sources and Nature of Wastes

In a recent release (1), the U. S. Atomic Energy Commission states that there are two major sources of radioactive waste:

1. The production phases of the national atomic energy program—the huge separation plants and the nuclear reactors.

2. The laboratories and hospitals where radioactive materials are used for research tools for medical treatment.

In the explosion of an atomic bomb radioactive products may be released which may produce additional radioactive wastes.

Nuclear Reactors and Separation Plants

Before uranium or other fissionable ores are ready for exposure to neutron bombardment in the pile the materials must be processed. It is only after they are subjected to neutron bombardment that the highly radioactive materials are produced. Each atom which undergoes fission normally produces two fission products. Experiments show that the process is asymmetric and produces fission products that can be classed as a light and a heavy group (2). Usually included in the light group are elements of atomic number 36 through 44, and in the heavy group elements of atomic number 52 through 61. Many of these are fairly long-lived and are listed in Table I. Fission product yields for U^{233}, U^{235}, and Pu^{239} have been published (2).

TABLE I.—Some Long-Lived Products of High Yield[1]

Fission Product	Fission Yield (%)	Half-Life	Beta Energy (Mev.)	Gamma Energy (Mev.)
		(a) LIGHT GROUP		
$_{36}Kr^{85}$	0.24	10 years	0.74	No
$_{38}Sr^{89}$	4.6	53 days	1.50	No
$_{38}Sr^{90}$	5	25 years	0.6	No
$_{39}Y^{91}$	5.9	57 days	1.53	No
$_{40}Zr^{95}$	6.4	65 days	0.39	0.73
$_{43}Tc^{99}$	6.2	9.4×10^5 years	0.3	—
$_{44}Ru^{103}$	3.7	42 days	0.2	0.56
$_{44}Ru^{106}$	0.5	1 year	0.03	See text
		(b) HEAVY GROUP		
$_{52}Te^{129}$	0.19	32 days	1.8	Xray, 0.3, 0.8
$_{53}I^{131}$	2.8	8 days	0.60	0.37
$_{54}Xe^{133}$	6	5.3 days	0.35	0.08, 0.03
$_{55}Cs^{137}$	6	33 years	0.5, 0.8	0.7
$_{56}Ba^{140}$	6.1	12.8 days	1.0, 0.4	0.5
$_{58}Ce^{141}$	6	29 days	0.55	0.21
$_{59}Pr^{143}$	6	14 days	1.0	No
$_{60}Nd^{147}$	2.6	11.0 days	0.4, 0.9	0.58
$_{61}Pm^{147}$	2.6	4 years	0.2	No

[1] From reference (2).

Chemical processing is necessary to separate the more valuable fission products for isotopic use in medicine and industry. To reduce the activity by natural decay, the remaining substances are discharged to waste tanks, where they are stored. If it can be done economically, storage is desirable to eliminate the discharge of those radiosotopes for which uses have not been found as yet, but for which future research may find use.

Where large volumes of water are required for cooling the pile, as at Hanford, Wash., disposal of the radioactive cooling water is a problem. To minimize the amount of induced radioactivity, the cooling waters are pretreated for the removal of such elements as iron, chlorine, calcium, and sulfur.

Isotope Usage

During the past few years isotopes have found wide usage in the medical and industrial fields. The extent of this use may be illustrated by data (Figure 1) giving the number of monthly shipments from the Operations Division, Oak Ridge National Laboratory. Since the first shipments in August, 1946, the increase has been continuous and rapid. It will be seen that the present rate of shipments is of the order of 700 per month, and by the end of July, 1950, a total of 16,030 shipments (project, non-project, and foreign) had been made. The isotopes most frequently shipped, and which accounted for approximately 75 per cent of the total shipments, were P^{32}, I^{131}, C^{14}, and Na^{24}.

In general, small amounts (microcurie and millicurie quantities) of radioactive materials are used in tracer experiments. Therefore, the wastes resulting from their discharge are small in volume and low in activity.

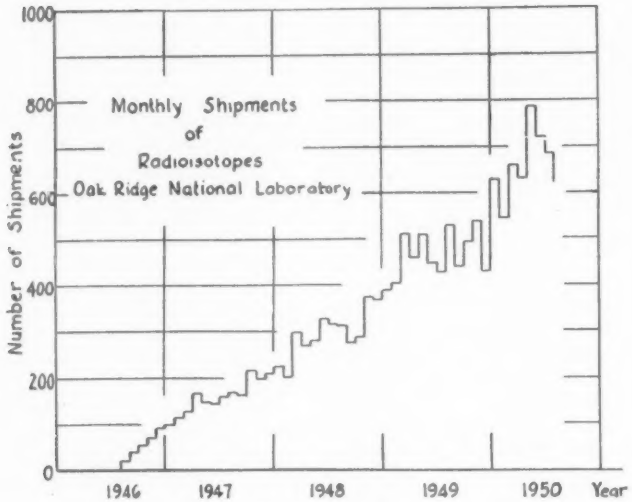

FIGURE 1.

Larger quantities (both in volume and activity) may be discharged from hospitals, where isotopes are finding widespread use as therapeutic agents.

Atomic Bomb Explosion

In addition to the radioactivity released in the explosion of an atom bomb, the neutrons discharged will produce activity in other substances. This activity (called "induced activity") will be quite variable, depending primarily upon the elements in the vicinity of the explosion and the type of blast (air, subsurface, or water). Radioactive wastes may result from the direct deposition of radioactive particles into watercourses or from the flow of wastes produced in the decontamination of buildings, equipment, etc., where water is used as the decontaminating agent. Except that there may be a greater variety of radioactive materials, the techniques which may be applied to the treatment of these wastes will be similar to those proposed for treating radioactive wastes from other sources. It is not believed that these wastes will constitute too serious a hazard, inasmuch as water treatment techniques (coagulation, filtration, softening, etc.), if available, will certainly decrease the amount of activity in any waters used for potable or industrial purposes.

Removal of Radioactivity

Control of wastes at their source is just as important in the treatment and disposal of radioactive wastes as in the treatment and disposal of domestic and industrial wastes. Until more is learned of what occurs, the discharge of radioactive materials into streams should be considered as a last resort and should be looked on with great disfavor. Little information is available concerning the processes involved in the concentration of radioactive substances by specific muds and soils, by benthos in the stream, by plankton, and by other flora and fauna which may spend part or all of their life cycle in the receiving stream. As shown by Ruchhoft (3), heavy concentrations of plutonium are adsorbed by activated sludge. Considerable unpublished data are available which indicate that muds, clays, activated car-

bons, etc., have an affinity for adsorbing certain radioactive materials.

Of the methods known to sanitary engineers and chemists for treating domestic and industrial wastes, the following have been suggested as possible modes of attack in solving problems incident to the treatment and disposal of radioactive wastes:

1. Evaporation.
2. Carrier precipitation (coagulation).
3. Sand filtration.
4. Ion exchange (natural clays and synthetic resins).
5. Electrodialysis.
6. Metallic displacement or scrubbing.
7. Differential volatility.
8. Electrolytic separation.
9. Solvent extraction.
10. Biological processes.
11. Crystallization.

These specific treatment methods as they apply to the removal of radioactive materials are noted hereinafter.

Evaporation

For the concentration of large volumes of wastes containing small amounts of radioactive materials, evaporation, although expensive, will remove practically all of the activity from the liquid fraction and will concentrate that activity in the solid residue or slurry. It is reported (4) that a decontamination factor of at least 100,000 is possible by this method. To permit disposal as a solid, and as a means of reducing the amount of space required for storage of radioactive materials, evaporation is desirable.

Carrier Precipitation

Carrier precipitation, or coagulation, is used extensively in the treatment of many industrial wastes, and has been adapted to the removal of certain radioactive materials. For the removal of arsenic, antimony, molybdenum, selenium, tellurium, and cerium, coagulation has been applied with varying success; however, with ruthenium and plutonium removals were very satisfactory. In many instances, coagulation was most effective at high pH values. Studies have been made at the Oak Ridge National Laboratory in which routine and special coagulation techniques were applied to the removal of specific isotopes from water solutions to which radioactive chemicals had been added. Using routine alum and lime coagulation, Placak and Lyle (5) obtained removals of specific isotopes, as shown in Table II. As a study indicated that there appeared to be more insoluble phosphates than hydroxides, Lauderdale (6) carried out experiments in which he employed a modified phosphate coagulation technique. The studies were carried out at a pH of about 11.5, using up to 200 p.p.m. Na_3PO_4 or KH_2-

TABLE II.—Alum Coagulation Results[1,2]

Element	Removal (%)	Remarks
I^{131}	Up to 10	Addition of small amounts of Cu, Ag, or C increased removals to 75 per cent.
Pu	98 plus	
Sr^{89}	10	Increasing turbidity from 50 to 1,000 p.p.m. increased removal efficiencies to 50 per cent.
Y^{91}	45	Using NaOH as alkali.
	98	Using Na_2CO_3 as alkali. Turbidity influencing factor also. For turbidity ranges of 50 to 1,000 p.p.m. removals ranged from 17 to 82 per cent.
Ce^{144}	98	Turbidity also influencing factor. For turbidity ranges of 50 to 1,000 p.p.m. removals ranged from 70 to 86 per cent.
Sr^{90}-Y^{90}	98 for Y 10 for Sr	On standing, more of the Y daughter formed from Sr.

[1] After Placak and Lyle (5).
[2] Essentially similar results obtained using iron as a coagulant.

TABLE III.—Phosphate Coagulation Results[1]

Element	Removal (%)
Zn^{65}	99 plus
Sr^{89}	98
Y^{91}	99 plus
Sb^{124}	67
Ce^{144}	99 plus
W^{185}	10

[1] After Lauderdale (6).

TABLE IV.—Pilot Plant Results[1]

Element	Treatment	Removal %
P^{32}	Coagulation with alum plus sedimentation	85
	Coagulation with alum plus sedimentation plus filtration	96 to 98
I^{131}	Coagulation with alum plus sedimentation (sodium silicate also used)	<1
	Coagulation, sedimentation plus filtration	<1
	Coagulation (alum, sodium silicate, alkali) plus carbon (5 p.p.m.)	15
	Coagulation (alum, sodium silicate, alkali) plus carbon plus filtration	25

[1] After Straub (7).

PO_4 and lime. Some typical results are indicated in Table III. Using pilot plant equipment having a capacity of approximately 1,000 l. per day, the writer (7) studied the removal of P^{32} and I^{131} by conventional water treatment units (coagulation, settling, and filtration). Removals are indicated in Table IV. At the Massachusetts Institute of Technology similar results were obtained for the removal of P^{32} by conventional water treatment units.

Sand Filtration

Although little information is available on the removal of radioactive substances by sand filtration, unpublished communications indicate that many of them may be removed by adsorption on sand grains. In the filtration of P^{32} and I^{131} experience had shown that the former was removed by filtration, as shown in Table IV, but that there was no measurable removal of the latter.

Ion Exchange

With the newer high-capacity cationic and anionic synthetic resins, many radioactive elements may be removed from large volumes of dilute wastes. Unpublished information (8) indicates that sodium, barium, and lanthanum are removed in cationic resin columns, and that tellurium and molybdenum are removed in anionic resin columns. The work of others indicates that under suitable conditions strontium, cesium, cerium, and the rare earths may be removed by cation exchangers. It is believed that ion exchange columns may have a very definite use as polishing units following the removal of gross radioactive contaminants by coagulation or carrier precipitation and filtration in the conventional type water treatment units.

Natural soils and clays are known to take up radioactive elements by adsorption. For the removal of radioisotopes from a mixed fission waste, Lauderdale (6) used local kaolinitic and montmorillonitic clays as adsorbing agents. Although the dosages of clay required were very large (to 50,000 p.p.m.), removals of 80 to 85 per cent were obtained. Other soils have been shown to adsorb plutonium, strontium, yttrium, cerium, and praseodymium. As mentioned earlier, P^{32} was taken up during filtration in a conventional type water treatment plant. Acid and alkali washes were found effective for eluting the adsorbed substances.

Metallic Displacement or Scrubbing

The technique of metallic displacement or scrubbing has been applied successfully to the recovery of ruthenium and other substances.

Electrodialysis, Electrical Separation, and Differential Volatility

As they apply to the treatment of radioactive wastes, no applications of the techniques of electrodialysis, electrical separation, and differential volatility are known to the writer.

Biological Processes

By extraction and concentration on aerated activated sludges, Ruchhoft (3) was able to demonstrate reductions of about 96 per cent in the alpha activity of plutonium as a result of

single-stage treatment. Somewhat similar results have been obtained in preliminary studies by the writer (7) in the removal of I^{131} by aerated and stirred activated sludges. Reid, at Johns Hopkins University, has studied the accumulation of P^{32} and I^{131} by slimes found in sinks, traps, and drains.

If the radioactive materials are long-lived and are retained in the sludge throughout the sludge treatment period, their accumulation may pose a serious hazard. Dried digested sludges, which are used as fertilizers, frequently are spread on park and golf course lawns. As a result, hazardous concentrations of radioactive materials may occur.

Crystallization

Cook and Wilkinson (9) report that it may be possible to freeze out a large fraction of the water, leaving the radioactive materials in concentrated solution, but that this method had never been investigated. The writer (7) has made some preliminary study in which very small samples (volumes to 200 ml.) were used and has found that concentration does take place. Concentration factors approaching 10^2 were obtained. Additional equipment has been procured for study of samples of much greater volume. Crystallization is not restricted to separation of solids by freezing alone, but may be applied to many forms of chemical reactions.

Conclusions

Many of the methods available for use in the treatment of industrial wastes may be utilized in the treatment of radioactive wastes. However, it must be remembered that, just as in sewage and industrial waste treatment, separation of the wastes into their liquid and solid fractions and discharge of the innocuous fraction does not solve the problem. The residue remains for disposal. All that can be accomplished is to concentrate the radioactive fraction into a smaller volume to permit disposal either as a sludge or a slurry. Where incineration is possible, providing precautions are taken to prevent contamination by volatile gases or fly ash, further concentration or reduction in volume may be obtained. The reduced volume of solid material then may be placed in suitable containers and buried in controlled areas or stored for decay or future recovery.

Further, it should be noted that waste treatment is an integral part of any technological process and procedures for treatment of the liquid wastes should be studied and solved prior to adoption of the proposed process.

Acknowledgment

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CHEMICAL WASTE DISPOSAL AT VICTORIA, TEXAS, PLANT OF THE DU PONT COMPANY *

By H. W. de Ropp

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Several years ago the Du Pont management adopted a policy of not authorizing new plant construction until adequate provision for waste disposal had been incorporated into the design. Work on a new manufacturing process, it was decided, was not to be considered complete until all questions of waste had been answered to the satisfaction of the company and public stream protection agencies.

This posed a real challenge to the chemists and engineers responsible for the company's new plant construction. It is doubtful, however, if the challenge was greater at any of the locations where the company has been building new plants than it was at Victoria, Tex., on the banks of the Guadalupe River, where a plant is being built to manufacture nylon chemical intermediates.

Here the river flow, in the light of the company's pollution abatement policy, presented a specific problem. The river is adequate for cooling and process-water requirements, but a flow greater than the daily minimum of 165 sec.-ft., established in 1917, would have been highly desirable, to say the least.

There are seven categories of waste at Victoria; to handle them adequately calls for a non-profit outlay of $1,600,000, an investment in community respect which a company wins by being a good neighbor. Of this amount, $460,000 is being spent in a large-scale experimental venture in subsurface handling of chemical plant wastes. For this portion of the project, the company took a financial risk beyond the initial cost, as there is no certainty at this time that the deep well will function as expected and an alternative means of disposing of some wastes may yet have to be found.

It is the purpose of this paper to discuss in some detail how it is intended to dispose of various wastes at Victoria. It is hoped that the facilities at the plant will prove to be sufficiently complete and effective to serve as a guide at other locations where Du Pont might have a similar problem.

Types of Wastes

Initial operation of the originally projected manufacturing installations at Victoria is scheduled for late fall of 1950, but additional construction authorized since work on this project was begun will not be completed until the spring of 1952. By that time 19 manufacturing and administrative buildings will have been erected on the 1,700-acre site and the plant will have about 550 employees.

Just as an agriculturist looks upon a weed as a plant out of place, a waste may be defined as a material out of place. If syntheses were perfect, industry would not be confronted with waste disposal problems—conversions and yields would be 100 per cent. Unfortunately, techniques have not been perfected to this extent. Invariably, means must be devised for disposing of annoying, useless by-products.

Wastes at Victoria fall into the following categories:

1. Sanitary.
2. Dilute aqueous solutions.
3. Cooling water. (This is not nor-

* Presented at 1950 Annual Meeting, Texas Water and Sewage Works Association; College Station, Tex.; March 12–16, 1950.

mally considered a waste but under certain conditions it may become contaminated.)

4. Organic liquids.
5. Gaseous wastes.
6. Organic solids and trash.
7. Concentrated aqueous solutions.

Sanitary

The sanitary waste disposal plant, which has been approved by the state authorities, consists of an Imhoff tank, sludge drying bed, and lagoon. It was designed for an ultimate capacity well above the number of people who will work at the plant. This unit is now in operation.

Dilute Aqueous Solutions

There are several dilute aqueous solutions, totaling an estimated 70,000 lb. per hr., which may at times carry contamination. These wastes originate from wash-down of paved floors, steam jet condensate, and process waters containing small quantities of salt and miscellaneous organic compounds. In view of the varying composition of these waste-water discharges, it is impossible to assign definite percentage values to the contaminants. The best estimates, however, indicate a sodium chloride content of 0.2 per cent; amine-type compounds, 0.06 per cent; and miscellaneous, including benzene, 0.1 per cent. It is proposed, initially at least, to resort to solar evaporation. Analyses of rainfall and evaporation rates at Victoria indicate a net evaporation gain over rainfall of about 16 in. per year. A 64-acre area with 5-ft. dikes is being provided initially in order to measure actual evaporation. One year's input of wastes can be accommodated in this area if no net evaporation above rainfall occurs. Test holes made in the area indicate a continuous layer of bentonite, which will insure against seepage of wastes into fresh ground waters.

Should this disposal method prove impractical, other methods will be used, such as spray evaporation in an incinerator, submerged combustion, and subsurface disposal. Insofar as flooding of the Guadalupe River is concerned, the records of the U. S. Army Engineers, up to November, 1948, show a maximum flood crest of 29 ft. at the north end of the plant site. The elevation of the waste evaporation pond is 73 ft.

Cooling Water

Although special precautions are being taken to prevent process materials from entering the plant cooling water, it was considered desirable to provide two large water retention reservoirs, which will fill and discharge on a cyclic basis, permitting a check to be made of water quality before release to the river. These so-called "passport" ponds will have capacities of 10 m.g. each and will operate on an 8-hr. cycle. In the unlikely event that cooling water becomes contaminated, it will be pumped to the 64-acre solar evaporation pond.

Organic Liquids

All organic liquid wastes, estimated at 5,100 lb. per hr. and consisting of hydrocarbons, low-boiling and high-boiling degradation products, and tars —the compositions of which have been established only in part—will be transported in corrosion-resistant tank wagons to a steel-incased refractory-lined incinerator. The products of combustion, largely carbon dioxide and water, will discharge from a 175-ft. brick-lined stack. The stack height has been calculated to provide adequate dispersion of the products at 1-m.p.h. wind velocities. Several days' liquid waste storage capacity will be provided to permit shutdown of the incinerator for routine maintenance.

Gaseous Wastes

Combustible waste gases, largely hydrocarbons and carbon monoxide, will be burned under the boilers and the

combustion products discharged from a 100-ft. stack. Other waste gases, because of variable composition, hence variable B.t.u. content, will be burned in the incinerator.

Trash and Solids

Trash and solid process wastes (largely coke) will be disposed of in a burning pit. Solid process wastes will average 600 lb. per day. They will be delivered to the burning pit twice a week as a 1-ton load. Plant trash will be burned daily.

Concentrated Aqueous Solutions

The combined effluent from three of the process flows totals about 83,000 lb. per hr. It will contain about 16 per cent sodium chloride, 0.5 per cent metallic salts, and upwards of 1 per cent of organic compounds consisting of miscellaneous degradation products. Although the concentration of organic chemicals in the effluent is reasonably low, its disposal is complicated by the high sodium chloride content.

Inasmuch as Texas has successfully developed subsurface disposal of the saline brines obtained as a troublesome by-product in oil field operation, it appeared that a similar approach might be used in disposing of the saline wastes at Victoria. It was recognized, however, that in the oil fields the brine returned underground is essentially the same as that obtained, whereas it was now proposed to introduce chemical, man-made wastes foreign to the underground environment. Because the drilling of a deep well into the salt brine strata is an expensive undertaking, and because the successful outcome of the proposal involved a considerable calculated risk, the following stepwise program was developed.

First, expert information was obtained from a geologist familiar with local formations and state regulations. He concluded that the compatibility of the wastes with the underground brines and strata could be determined only by drilling a well at the plant site, obtaining the necessary sand and brine samples, and conducting extensive laboratory tests. He did not feel it safe to obtain brine and sand samples from wells at other localities but from similar strata, as the vagaries of underground formations would not give a positive answer. He also emphasized that stringent precautions would be necessary, such as cementing the well and providing corrosion-resistant casing, in order to prevent contamination of the shallower fresh-water strata.

The subject of subsurface disposal was then discussed thoroughly with the state authorities. The proposal was explained to the Railroad Commission; the Game, Fish and Oyster Commission; the Board of Water Engineers; and the State Health Department. All expressed great interest in the proposal and, in fact, wrote the company, urging it to proceed with this development as outlined to them. It is doubtful whether subsurface waste disposal would have been undertaken at Victoria without the encouragement and help of this group. On the strength of the favorable reaction, it was decided to take the financial risk involved in drilling the well.

At the present time, the well is equipped as follows:

1. A 10¾-in. casing protected with Tube-Kote has been cemented in at the 2,448-ft. level.

2. A 7-in. casing, also protected with Tube-Kote, extends from the surface to the 4,822-ft. level. It is cemented in from the 1,987-ft. level to the bottom.

Eventually a "production string" of 3½-in. O.D. No. 8 metal tubing and a packer will be installed. There are some 400 or 500 ft. of permeable unconsolidated sands that appear suitable to receive the wastes. Perforation of the casing and the cement will be undertaken shortly before operations begin at Victoria.

Meanwhile, extensive sampling of

the brines and sands and exhaustive tests in the laboratories have demonstrated that, with minor treatment, the wastes will be well-behaved when pumped into their new environment. The brine treatment plant will include:

1. pH adjustment to bring the waste from the acid to the alkaline side.
2. Aeration to oxidize heavy metals and cause them to precipitate in the form of hydroxides.
3. Chlorine treatment to prevent algae growth.
4. Settling basins to remove the bulk of the precipitate.
5. Clarification by filtration.
6. pH adjustment to render the wastes slightly acid.
7. Pumping facilities.

This follows, in general, the brine treatment used at Kilgore, Texas, by the East Texas Salt Water Disposal Company, whose helpful suggestions were greatly appreciated.

It should be mentioned that normal interruptions to continuous operation of the well have been anticipated. In the event of a breakdown in the brine treatment plant or well injection facilities, or plugging of the well proper, a 59-acre, diked impounding area is being provided where the brine may be stored temporarily. This area will accommodate a 6-month output of brine at a depth of 21 in. inside the 5-ft. dike, assuming evaporation to equal rainfall.

As soon as the well is a proven, unqualified success, a second and possibly a third well will be drilled. In the unlikely event that subsurface injection of the wastes proves to be unworkable, storage of brine will not be considered as the ultimate disposal method, but other means, such as spray-drying or submerged combustion-evaporation, will be installed.

River Survey

From an entirely technical point of view, a very interesting step was taken to ascertain the present condition of the Guadalupe River. In August, 1949, the Academy of Natural Sciences of Philadelphia undertook, at the company's request and expense, a "biodynamic survey" of the river near Seguin, and also at a point below the site of the plant pumping station. The rather formidable term, "biodynamic survey" means determination and analysis of the number of different species of fish, insects, arthropods, rotifers, mollusks, protozoa, and algae in the river at various sampling points. By plotting the findings on charts and comparing them with similar charts made for a healthy stream having the same general characteristics of hardness, turbidity, and groups of organism, it is possible to classify the surveyed stream as healthy, semi-healthy or polluted. The Academy reported that a normal biodynamic cycle seemed to be functioning in the Guadalupe River. The survey has just recently been repeated as a check against the first.

Although the biodynamic survey is a comparatively new approach for determining the condition of a stream, it could possibly become the future yardstick for the classification of streams, supplementing the present B.O.D. criterion, which some authorities regard as unsatisfactory when applied to certain chemical wastes. This new stream survey method has been described adequately elsewhere (1).

Any plant operation is subject to human failures, and operating errors may be made at Victoria that will cause embarrassment. By intensive repetitive operator training, however, and by the use of all the technical skill available it is hoped to minimize, if not eliminate, such occurrences.

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Stream Pollution

THE FLUSHING OF TIDAL ESTUARIES *

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Methods developed at the Woods Hole Oceanographic Institution to determine the accumulation of river water within an estuary and the rate of its transport through the estuary have been described elsewhere (1)(2)(3). The survey data showed that estuaries do not flush as rapidly as the tidal prism calculation would indicate, but the reasons for the discrepancy were unknown. This paper attempts to explain the discrepancy by presenting a modification of the tidal prism concept which produces results agreeing closely with observed conditions in a variety of estuaries.

The tidal prism concept has been used to evaluate the ability of an estuary to disperse introduced pollution. The tidal prism is equal to the difference between the volumes of water in the estuary at high and low tides. Part of this volume is contributed by river flow, part by water which must enter through the seaward boundary of the estuary on the flooding tide. As one moves seaward from the river, the proportion contributed by the ocean becomes much greater than the river flow. The volume of water entering the estuary from the ocean is presumed, in the classical application of the tidal prism concept, to be the volume available for the dilution and removal of the pollution added during each tidal period. This presumption involves the following tacit assumptions:

1. The entering water mixes completely and uniformly with the water present in the estuary at low tide.
2. The volume of water moving seaward on the ebb tide escapes and is not returned to the area on the next flood tide.

Under actual conditions neither of these assumptions is correct. A horizontal gradient of salinity is always observed, ranging from negligible values in the river to maximum values at the seaward end. This shows that horizontal mixing is not complete. Because tidal currents are oscillatory, some of the water removed on one ebb tide is always returned on the next flood tide. The practical problem is to define the volume of water which escapes, on the ebb tide, through any cross section of the estuary, and does not return on the succeeding flood tides.

The proposed modifications of the tidal prism concept permit the calculations of tidal exchanges between various parts of the estuary, the total accumulation of river water, or its contained pollution, within the estuary, and the average length of time the river water has been in the estuary. The total volume which escapes on the ebb tide through various cross sections, and does not return on succeeding flood tides, is also calculated. It is this escaping volume, rather than the total volume of the tidal prism, which is available for the dilution of introduced pollution.

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Theoretical Considerations

An estuary may be defined as a body of water in which the river water mixes with and measurably dilutes sea water. The inner end of the estuary can be precisely defined as the cross section above which the volume of water involved in raising the height from the low tide level to the high tide level is all contributed by river flow. On the flooding tide there will be no net exchange of water through this cross section, as the river flow contributes all of the water necessary to fill the intertidal volume. Thus, the water above this cross section should be completely fresh. On the ebb tide there is a net loss through this cross section of a volume of fresh water equal to the volume introduced by the river during a tidal cycle. It will be noted that this is a dynamic, and not a geographic boundary, and implies that the inner end of the estuary moves upstream and downstream with changes in the volume of river flow. No attempt is made to define the seaward end of the estuary, as the salinity of the water approaches the salinity of pure sea water gradually. The seaward boundary can be drawn at any convenient location and the area enclosed is considered as the estuary.

It is assumed that there will be a steady state distribution of fresh and salt water throughout the estuary if the river flow remains constant. During each tidal cycle the salinity at any location varies with the stage of the tide, but on successively similar tidal stages the salinity returns to substantially the same value. Figure 1 shows an example of the variation of salinity with tidal time for three locations in Raritan (N. J.) Bay. The lower curve was obtained nearest the river mouth, where the lowest salinities and the maximum variation during the tidal cycle were observed. The other two curves show conditions at

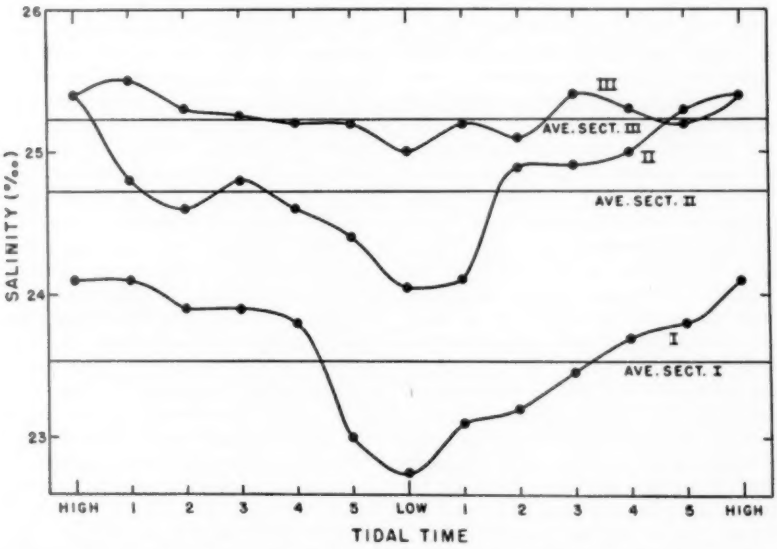

FIGURE 1.—Average salinity variations during a tidal cycle for three cross sections in Raritan Bay. Section I was 1.8 mi., Section II 2.9 mi., and Section III 4.6 mi. from the mouth of the Raritan River.

greater distances from the river mouth, where the salinities were higher and the variations were smaller. In each case the salinity at successive high tides returned to approximately the value previously observed.

In order to maintain a steady state distribution of this sort, two conditions must be met at every complete cross section of the estuary:

1. There must be a net seaward transport, during any tidal cycle, of a volume of fresh water equal to the volume introduced by the river in the same period of time.
2. There must be no net exchange of salt through the cross section during the tidal cycle.

It will be recognized that these conditions do not define the total circulation, but do define the net exchange which is the result of the circulation. The circulation of salt water, for example, may be considerable, but the quantity of salt introduced by the more saline water entering on the flood tide must be exactly balanced by a loss of an equal quantity of salt in the mixed water escaping on the ebb tide.

The tidal prism concept tacitly assumes complete mixing of the water entering on the flood tide with all of the water present in the estuary at low tide. The velocities of tidal currents, however, are generally not great enough to transport the water more than a fraction of the length of the estuary. It seems logical to assume that the maximum length of the estuary over which complete mixing is possible will be determined by the average excursion of a particle of water on the flooding tide. In the proposed modification of the tidal prism concept, subdivision of the estuary into segments defined by the average excursion on the flood tide is an essential and integral part of the treatment.

A chart of Raritan River and Bay, illustrating the volume segments limited horizontally by the width of the estuary and by the average excursion on the flood tide, is shown in Figure 2. In this estuary, 15 volume segments are so defined. The tidal flushing theory assumes complete mixing of the water in each of these segments at high tide. On the ebb tide, the water making up the local intertidal volume of each segment permanently escapes into the adjacent seaward segment. The flushing is thus accomplished by a series of tidal exchanges, with part of the river water, and its contained pollution, moving one segment seaward each tidal cycle.

It should be pointed out that it is unnecessary to have direct current measurements in order to determine the length of the segments in an estuary. The average excursion can be obtained directly from the volumes of water in the estuary at low and high tides. Each segment is defined so that the volume it contains at high tide is equal to the volume of tidal prism water which must enter through the seaward boundary on the flooding tide. If this entering water were to act as a piston, displacing and pushing upstream the low tide water previously present, the distance traveled would be equal to the average excursion on the flood tide. The low tide water displaced equals the volume of the total tidal prism for the remainder of the estuary, and fills the adjacent landward segment at high tide. Thus, the low tide volume of each segment equals the high tide volume of the adjacent landward segment. A definition of the inner end of the estuary has been given above. The segmentation may be started at this boundary, the location of which is determined by the river flow. Near this boundary the size of the segments varies with different river flows. As the tidal prism volume increases for successive seaward boundaries, however, the effect of differences in river flow becomes negligible. This method of segmentation of estuaries is described in more detail elsewhere (4).

If it is assumed that the water pres-

ent in each of the volume segments is completely mixed at high tide, the proportion of water removed by the ebbing tide is given by the ratio between the local intertidal volume (that part of the tidal prism within each volume segment) and the local high tide volume. This is defined as an exchange ratio, r, having the value

$$r_n = \frac{P_n}{P_n + V_n}$$

in which P_n is the intertidal volume and V_n is the low tide volume of the nth segment.

The river water present in each segment is made up of varying proportions of water that arrived at the location under consideration during a series of tidal cycles. Using the tidal exchange ratio, the proportion of river water of various tidal ages removed during each cycle, and the proportion

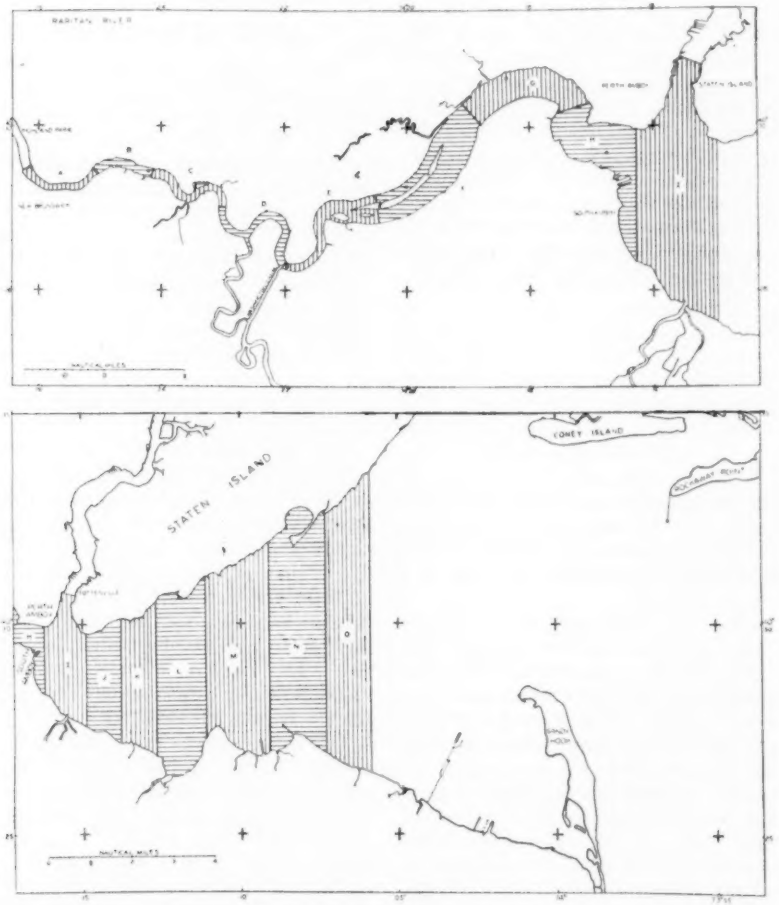

FIGURE 2.—Subdivision of Raritan River and Bay into volume segments defined horizontally by the estuary width and the average excursion of a water particle on the flood tide. (River chart scale about twice that of bay chart; volume segment I identical in each.)

left behind, may be summarized as follows:

Age (tidal cycles)	River Water Removed	River Water Remaining
1	$r R_1$	$(1-r)R_1$
2	$r(1-r)R_2$	$(1-r)^2R_2$
3	$r(1-r)^2R_3$	$(1-r)^3R_3$
k	$r(1-r)^{k-1}R_k$	$(1-r)^kR_k$

in which R_1, R_2, R_3, . . . , R_k are the volumes of river water which arrived 1, 2, 3, . . . , k tidal cycles prior to the time considered.

If the river flow is constant, all values of R are equal and steady state conditions may be presumed to exist. The total volume, Q_n, of river water accumulated within any volume segment, n, of the estuary at high tide is then the sum of the remaining volumes given in the final column above. Because the equation is written for the high tide condition, there is also present one volume of river flow which has not yet been depleted. That is,

$$Q_n = R[1 + (1-r) + (1-r)^2 + (1-r)^3 + \cdots + (1-r)^k]$$

This series will approach, as k becomes large, the limit:

$$Q_n = R\,\frac{1-(1-r)^k}{r}$$

Because $(1-r)$ is always less than unity, $(1-r)^k$ approaches 0 after an infinite number of tidal cycles, and the sum can be reduced to:

$$Q_n = \frac{R}{r_n}$$

It will be remembered that one qualification of the steady state distribution was that the river water passing seaward through every cross-section on each tidal cycle must equal the volume of fresh water introduced by the river during the same period of time. The above relationship states that the volume of river water moving seaward is the product of the exchange ratio and the accumulated volume of river water; that is, $r\,Q$. It is readily seen that this product equals R so that this criterion of steady state distribution is satisfied.

This theory has been applied to three very different estuaries; namely, Raritan River and Bay, N. J., Alberni Inlet, B. C., and Great Pond, near Falmouth, Mass. These calculations and the comparison of the results with actual conditions observed during hydrographic surveys are given by Ketchum (4). The effect of incomplete mixing on the exchanges and accumulation are also discussed.

Age of the River Water

The river water present at any time in each segment of the estuary is a mixture of water which has accumulated during an infinite number of tidal cycles. The length of time various proportions of the water have been present is directly represented by the individual remaining volumes listed above. It is thus possible to determine the average age, in tidal cycles, of the river water in each segment. The importance of assessing the age of the river water is obvious in evaluating the distribution of oxygen, coliform bacteria, or any other substance subject to change with time.

The proportion of the river water left behind after being depleted by a series of tidal exchanges is shown in Figure 3 for segments characterized by different exchange ratios. The half-life of the water is the time when half of the river water introduced on one tide has been removed, and is indicated in Figure 3 by the horizontal dashed line. The half-life, for the exchange ratios selected, ranges from 0.4 tides for $r = 0.8$, to 6.5 tides for $r = 0.1$.

The mean age of the water is the average length of time required for the river water, and its contained pollution, to move through the segment. This has also been defined (3) as the flushing time, which is calculated, from the data of hydrographic surveys, by dividing the total volume of river water within the area by the volume of river water introduced each tidal

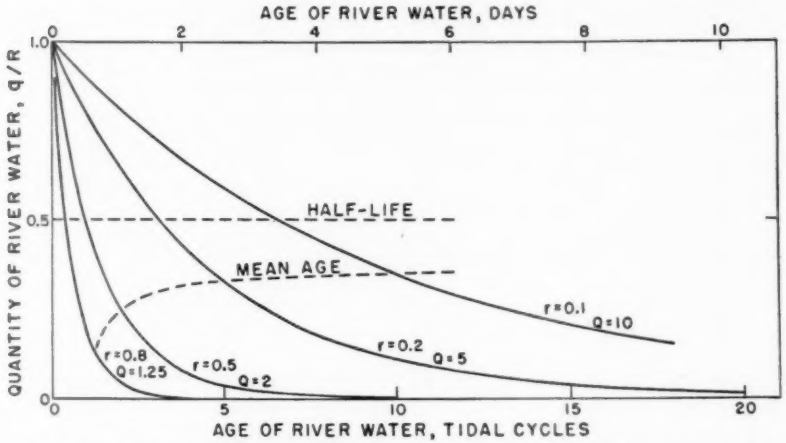

FIGURE 3.—Age composition of river water in estuarine segments characterized by various exchange ratios.

cycle. This ratio is numerically equal, in each volume segment, to the reciprocal of the exchange ratio previously defined. The mean age, or flushing time, illustrated in Figure 3 varies from 1.25 tides (for $r = 0.8$) to 10 tides (for $r = 0.1$).

The above discussion, and the data in Figure 3, are directly applicable only to the first segment of the estuary. The river water entering this segment each tidal cycle has not aged within the estuary, and can be considered new water. For each successive segment down the estuary the water entering on each tidal cycle has already been in the estuary for some time. The water entering the second segment, for example, has been within the first segment for an average length of time equal to its mean age. Similarly, the water entering each successive segment has been within the estuary for progressively longer periods of time. In order to determine the average total length of time the river water in any given segment has been within the estuary, the sum of the average times occupied in passing through all of the enclosed segments must be added to the mean age within the segment considered.

Procedure of Evaluation

The evaluation of an estuary for the disposal of pollution will be illustrated using data for Raritan River and Bay. This location was selected because survey data are available for comparison (1). It must be emphasized, however, that this paper is not primarily a description of a particular estuary, but of methods of evaluation applicable to any tidal estuary.

The first step in evaluation is to compute the distribution of fresh water for various volumes of river flow. In Raritan Bay this has been done for the maximum and minimum mean monthly flow during 1948. An additional calculation was made for the average flow for December, 1948, in order to permit comparison between the calculated and survey results. The cumulative volume of river water is plotted against the length of the estuary in Figure 4. The points, representing the accumulation calculated from survey data, agree closely with the calculated distribution for about 15 mi. of the estuary. The fact that the calculated accumulation of river water near the outer end of the estuary is less than the accumulation observed

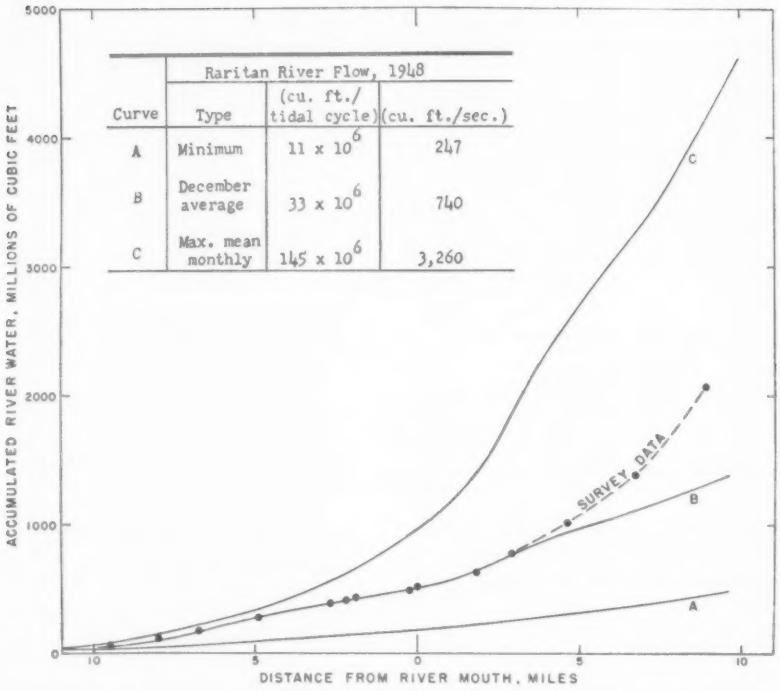

FIGURE 4.—Calculated accumulation of Raritan River water in estuary. Survey data from a hydrographic survey in December, 1948.

on the survey is probably an indication that mixing is horizontally incomplete in this part of the estuary (4). This low calculated accumulation will also be apparent in subsequent values, which are based upon these data. The total flushing times calculated from the data in Figure 4 range from 32 tides

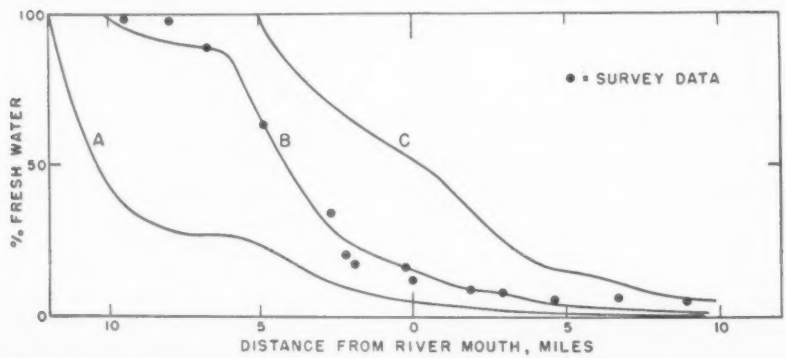

FIGURE 5.—Average percentage of river water in various parts of Raritan River and Bay for three rates of river flow listed in Figure 4.

(for maximum river flow) to 42 tides (for minimum river flow). The survey data indicate a flushing time for the entire estuary of 60 tides. It is of interest that 15 to 30 days are required, on the average, to flush the river water through this area.

The average proportions of river water at various points within the estuary also have been calculated (Figure 5) for the same three rates of river flow. The average proportion is determined by dividing the total quantity of accumulated river water in each segment by the high tide volume of the segment. The results of the survey made in December, 1948, are again used for comparison. All of the water is river water above the boundary defining the inner end of the estuary. This boundary moves a distance of almost 7 mi. downstream as the river flow changes from minimum to maximum values. Seaward from this boundary the proportion of river water decreases, reaching values ranging from less than 1 to almost 6 per cent of the total volume at the outer end. The higher proportion of river water is, of course, associated with the greater river flow.

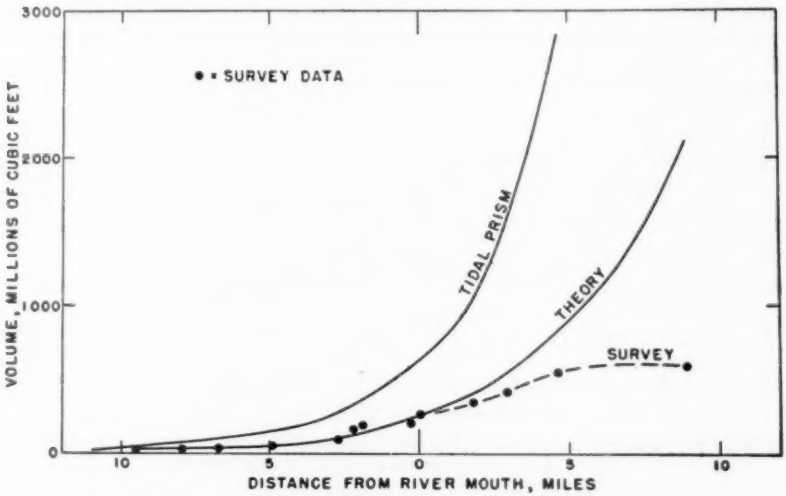

FIGURE 6.—Volume of the tidal prism, and escaping volumes computed from the theory and from survey data. (Tidal prism volume at 9 mi. is 9,200,000,000 cu. ft.)

As mentioned previously, the practical problem which must be solved in order to provide useful data for the sanitary engineer is to define the volume of water which escapes through each cross section and does not return on the succeeding flood tides. The tidal prism concept assumes that the entire volume of tidal prism escapes; it gives exaggerated estimates of the rate of flushing. The modified tidal prism calculation described in this paper assumes that the local intertidal volume in each segment escapes through the seaward boundary and does not return. This produces an escaping volume much smaller than the total tidal prism volume. The escaping volume can also be calculated from the salinity data of a hydrographic survey. At any location within the estuary the water present is a mixture of fresh and salt water. Enough of this mixture must escape on each tidal cycle to remove the volume of fresh water

contributed by the river in the same period of time. The total escaping volume can be obtained by dividing the river flow per tide, R, by the fraction of fresh water in the mixture, F; that is,

$$\frac{R}{F} = \text{Escaping Volume}$$

Thus, if the mixture contains 10 per cent fresh water ($F = 0.1$), 10 volumes of mixed water must escape in order to carry away one volume of fresh water.

These three methods of computing the escaping volume may be compared for the outer boundary of the first segment in Raritan Bay (Segment I, Figure 2). The total tidal prism volume at this location is almost 1,200,000,000 cu. ft. The local intertidal volume, which the tidal flushing theory assumes to be the escaping volume, is 390,000,000 cu. ft., or about one-third the volume of the total tidal prism. The survey data gave an average fraction of fresh water of 0.093, which, with a river flow of 33,000,000 cu. ft. per tidal cycle, produces an escaping volume of 355,000,000 cu. ft. It appears that the proposed theory gives an evaluation of the flushing of the estuary which closely approximates the actual conditions, whereas, in this location, the classical tidal prism method is in error by a factor of 3.

The total tidal prism volumes and the calculated escaping volumes for various locations in Raritan River and Bay are shown in Figure 6. The average December, 1948, river flow has been used to permit direct comparison with the survey data. Throughout the length of the river and the first 3 mi. of the bay, the calculated escaping volume corresponds closely with the escaping volume deduced from survey data. For the outer end of the bay the calculation produces an escaping volume almost six times as great as the escaping volume computed from survey data.

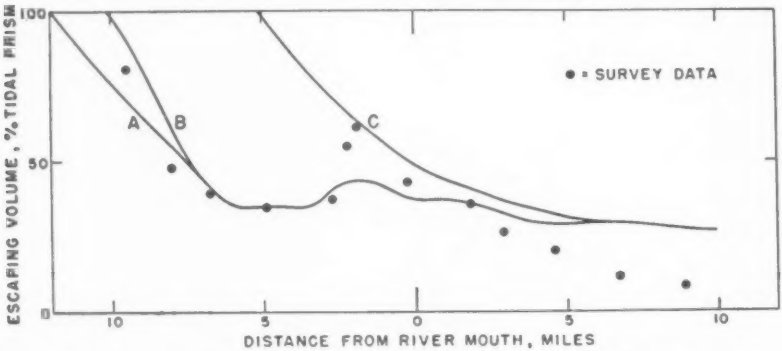

FIGURE 7.—Escaping volumes in Raritan River and Bay for three rates of river flow (see Figure 4) as percentage of tidal prism volumes.

The total tidal prism volume at this boundary, however, is almost 30 times as great as the escaping volume computed from the survey data.

The escaping volume can also be expressed as a percentage of the tidal prism volume. This presentation of the data is shown in Figure 7 for the three rates of river flow. The point where the escaping volume is equal to the tidal prism volume shows the location of the dynamic inner boundary of the estuary. The flushing of the inner end of the estuary varies greatly with variations of river flow. Near the outer end, however, the theory predicts that the flushing rate is independ-

ent of river flow. Presumably, flushing of this part of the estuary is determined primarily by tidal action. The calculated escaping volume varies from 100 per cent of the tidal prism volume at the inner end of the estuary, to about 26 per cent of this volume at the outer boundary. The escaping volume calculated from the survey data shows reasonably good agreement throughout most of the estuary, but falls to a value only 8 per cent of the tidal prism volume at the outer boundary. This indicates that the tidal flushing theory predicts exaggerated rates of flushing only at the seaward end of the estuary. In contrast, the classical tidal prism concept produced accurate predictions only where the water was completely fresh, and exaggerated the rate of flushing throughout the entire length of the estuary.

The comparison between the volumes available for dilution of pollution in the river and in the estuary should not be neglected in discussing these results. For the first segment in the bay in December, 1948, for example, the volume available on each tidal cycle for the dilution of pollution introduced into the estuary was more than 10 times as great as the volume of river flow per tidal cycle. At the outer boundary, the available diluting volume on each tidal cycle is 20 times greater than the river flow. It is obvious that the universal belief that estuaries are more effective in diluting and removing pollution than the tributary river was well founded, even though the tidal prism concept produced an overly optimistic evaluation.

Discussion

The empirical theory, upon which the calculations in this paper are based, has been described in more detail in a separate paper (4). The theory is not foolproof, and the original paper gives both details of the method of application and ways to check the accuracy of the results. The effects of incomplete vertical and horizontal mixing, which can greatly modify the distribution of river water, are also discussed. The calculations have been applied to only three estuaries. In two of the three, corrections for incomplete vertical mixing were necessary to produce a good correlation. Although the modified theory gives more realistic results than the classical tidal prism concept in the cases tested, much more experience is necessary in order to determine its general usefulness.

The basic data required for the application of the theory are the mean range of tides, the river flow, and the topography of the estuary. All of these are readily available for most estuaries. The theory permits the calculation of the following estuary circulation characteristics, which should be of value to sanitary engineers:

1. The concentration and quantity of river water in various parts of the estuary for various volumes of river flow. The dilution of any pollutant carried by the river water can be directly derived from these data.

2. The mean life of the river water in any segment of the estuary, and the average time required for the river water to reach any part of the estuary. Time-dependent processes, such as oxygen consumption or mortality of bacteria, can be studied using this information.

3. The total volume of water which escapes seaward, and does not return on succeeding flood tides, through various cross sections. This volume is the volume of water available for the dilution of pollution introduced directly into the estuary by sewer outfalls.

River water has been used as a tracer in describing the exchanges within the estuary. It is apparent that any water-borne pollutant will respond in a similar way to the forces and processes controlling the distribution of river water. From the distribution of river water, the distribution of any

pollutant within the estuary can be derived.

Acknowledgments

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DISCUSSION

By A. M. Rawn

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The author is to be congratulated for presenting a logical method of calculating the effective dilution of fresh water flowing into an estuary and also a means for determining the ratio of fresh to salt water at any location in the estuary if the physical characteristics of the latter, the rate of river flow, and the position of the tide are known. The fallacy of the tidal prism theory becomes immediately apparent upon examination of Mr. Ketchum's scholarly analysis.

Two factors not discussed at length by the author may, at times, set at variance the results predicted by his theory with what will actually be measured at a known location. One of these (1) is the tendency for fresh water, because of its lesser density, to stratify and flow over the top of the salt water, and the other is the tendency for the colder, heavier, sea water on the incoming tide to move shoreward under the overlying warmer waters and crowd them seaward.

As an example of the first of these two factors, the writer's staff analyzed a proposal to discharge primary effluent from a sewage treatment plant into the Long Beach, Calif., intermediate harbor. The proposal had been made following a study based on the tidal prism theory and the conclusions drawn indicated that the dilution would be so great as to render the effluent inoffensive in the harbor waters. When analyzed by a process which involved, in part, that described by the author and, in part, the stratification idea, the conclusions proved to be wholly fallacious. The "steady state" was of necessity disregarded and the tidal range influence computed.

The tidal prism theory led to the assumption that the entire increase in sea water from low tide to high tide was available for dilution in each tidal cycle. By contrast, as a result of the writer's analysis it was determined that new incoming sea water reached the area over the submerged sewer outlet only on 10 days in any 30-day period, and that mixed sewage and sea water reached the outlet from the intermediate harbor into the outer harbor in appreciable quantities only 12 days out of 30.

The stratification theory indicated that practically all of the sewage proposed to be discharged in the intermediate harbor would find its way

quite promptly, mixed with the sea water, into the upper 5 ft. of the 40-ft. depth of harbor water, and that for this reason some seven-eighths of the incoming tidal flow would be too far below the surface to contribute much to dilution. Also, only about 3 per cent of the incoming salt water, actually would reach the site of the outfall in an unpolluted condition, and, on the average, sewage or mixed sewage and sea water would be retained in the intermediate harbor an average of three days before escaping into the outer harbor.

Stratification of fresh water on salt water is aptly demonstrated where the Fraser River discharges into the Straits of Georgia. On one occasion during an inspection trip of these waters, the writer noted that the small boats' wakes were quite blue; whereas the surrounding waters had been turned completely brown by the muddy waters of the Fraser. The depth of stratification in this instance would be the upper zone marked in depth by the disturbance created by the small boats' propellors.

Another clear picture of the persistence of the stratification of fresh on salt water is obtained by an analysis of the salt waters in the vicinity of the mouth of the Fraser. The oscillatory motion imparted to the river by the extremes in tidal range permits the formation of fresh water islands overlying salt water in the straits and these fresh water islands preserve their identity for a number of days before becoming completely diffused in the upper strata of the underlying salt water. Their separation from one another is easily detected by salinity analyses.

The second of the factors which may affect the author's conclusions—namely, that of the flowing of denser waters underneath the lighter surface waters and displacing them from the bottom up, is believed by the writer to account for the clean-up of dead-end salt-water inlets into which crude sewage is constantly discharged. The writer is aware of one dead-end tidal inlet on the Pacific Coast extensively used for docking and shipping and into which, at the extreme inland end, is emptied a large quantity of untreated sewage and industrial waste. This harbor has a narrow mouth and expands then into a basin of considerable area. It has no stream of nonsaline water (excepting sewage) tributary to it. Nevertheless, the extreme inland waters, into which millions of gallons per day of crude sewage are emptied, are in pretty fair condition and putrefying sludge banks are not at all extensive. In this instance, it would seem that the only explanation for the extensive amount of diluting water which reaches the sewage is that the heavier, colder water travels upstream under the lighter, overlying strata, and that perhaps the combination of stratification and vertical displacement accounts for the presence of the cleaner sea water.

Evaluating the effect of stratification and bottom density currents is a difficult task, but that they are factors in the tidal flushing action can scarcely be questioned.

Again the writer wishes to congratulate Mr. Ketchum upon his excellent presentation of this sometimes confused—and, at times, confusing—phenomenon, and to express the hope that the tidal prism theory, with all of its fallacies, will no longer be substituted for the better and more accurate analysis which the author presents.

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DOMESTIC AND INDUSTRIAL WATER SUPPLY AND POLLUTION *

By L. R. Howson, *Chairman*, J. H. Allen, M. B. Cunningham, J. C. Frye, R. E. Lawrence, F. W. Mohlman, S. T. Powell, A. M. Rawn, and A. D. Weston

Task Committee No. 1, The Water Policy Panel, Engineers Joint Council

Domestic and Industrial Aspects of National Water Resources Policy

The use of the nation's resources for public water supply constitutes the highest and best use. Such use must have first priority in the consideration of water resources development.

The aggregate volume of water used for public water supplies is relatively small, being visualized by the statement that the public water supply requirements for the entire United States are but approximately 10 per cent of the flow in the Niagara River outlet from the Great Lakes. The total domestic and industrial use of water from public supplies is about one-fifth of that used by irrigation. Public water supplies use about 15,000 m.g.d., of which one-third, more or less, is used by industry. In addition, industries use approximately 5,000 m.g.d., which they individually develop, together with still larger quantities of recirculated and sea water.

Although comparatively small in amount, as compared to the total water resources, public water supplies are the most basic requirement for urban development. Urban life cannot exist except where adequate water resources of satisfactory quality are available for domestic and municipal purposes. Public water supply is the most universal of all uses of the national water resources—it affects every state and most cities and villages. Approximately two-thirds of the U. S. population now enjoys and is dependent on public water supplies.

Because a large proportion of the water supply requirements for domestic and municipal purposes is derived from surface sources and requires purification to make it of acceptable sanitary quality, it necessarily follows that pollution of streams from which water supplies are to be taken must be controlled within limits compatible with its purification for domestic use. Likewise, over considerable areas where, through the development of natural resources, brines and acid wastes are a by-product, their disposal must be such as to permit the use of the waters, where necessary, for its highest use; namely, that for domestic and municipal purposes.

Public water supplies are essentially local community problems. Only in a comparatively few cases are they statewide problems; in still fewer cases are questions of interstate policies involved. It is believed, inasmuch as the problems are essentially local, that public water supplies should be developed, regulated, and paid for by those using the services.

There would appear to be no valid reason for the federal government to develop water resources for public and municipal purposes at any place in the country. Water from public supplies is relatively so cheap (usually costing at the consumer's faucet less than 5¢ per ton or less than 2¢ per capita per day) that practically any community can have and finance a public water

* Appendix I of "National Water Policy," a statement of policy prepared under the auspices of the Water Policy Panel, Engineers Joint Council (June, 1950).

supply if it has the will to do so. It is believed that over 50 per cent of the residential water takers in the United States pay less than 1¢ per capita per day for their water.

Only a few public water supplies pose interstate problems. It is believed that those few where more than one state is involved introduce no problems directly at the federal level, but can best be solved by a compact of the states whose interests are affected, with federal participation in an advisory capacity or by limited legislation at the federal level in approving interstate compacts.

Industrial Water Supply

There are four sources of water upon which industry must depend to meet its present and future requirements. These are: (a) surface water, (b) underground water, (c) sea water, and (d) water reclaimed from industrial and domestic sewage. A water conservation program, either local or national in scope, designed to accommodate the increasing industrial requirements will prove inadequate unless all these sources are evaluated. One observer stated that "water shortages are due not to lack of water, but to lack of planning." There is much wisdom in this conclusion. Critical problems related to inadequate water supplies in many areas can be solved, however, if wasteful practices are discontinued, and if industrial requirements are adequately planned and reasonably regulated by state and federal control.

Availability of Water

The average annual rainfall over the country as a whole far exceeds any reasonable predicted demand for municipal and industrial water. It is estimated by the U. S. Weather Bureau that an average of about 30 in. of precipitation occurs annually over the United States. U. S. Geological Survey records show that about 21.5 in. of rainfall soon returns to the atmosphere due to evapo-transpiration and 8.5 in. runs off directly through streams, or through the ground and thence by streams, to the oceans. It is estimated by the U. S. Geological Survey that approximately 0.75 in. is intercepted by water users throughout the country. The total consumption is in the magnitude of from 100,000 to 150,000 m.g.d., of which industry uses 5,000 m.g.d. About 25,000 m.g.d. is taken from the ground through wells; the remainder is supplied by surface water. This consumption does not include salt-water usage from the ocean or salt water from underground sources (1).

Specific Water Uses

The quantity and quality of water requirements for miscellaneous industries vary so widely (see Table I) that each type of processing presents individual requirements which must be satisfied. However, practically all industrial uses of water fall within one or more of the following classifications:

1. Cooling.
2. Processing (entering into or contacting products manufactured).
3. Power generation.
4. Sanitary services.
5. Fire protection.
6. Miscellaneous (air conditioning, washing, etc.).

Of these uses, the demands for cooling water far exceed all others. For example, large individual electric generating stations will use 500,000 g.p.m. of water, or more, for surface condenser operations. It is obvious that such volumes of water are not obtainable from underground sources, but well water is frequently supplied as make-up water to cooling towers to replace evaporation losses. In some cases, even these requirements are appreciable; for instance, a 300,000-kw. generating station, now being planned, will require 6,000 g.p.m. of new water

TABLE I.—Estimation of Water Usage by Twenty Selected Industries[1]

Industry	Number of Establishments	Value Added by Manufacture ($1,000)	Production		Estimated Water Consumption	
			Number	Units	Gal. per Unit	Year 1947 (m.g.)
Steel (finished)	419	2,659,250	61,857,241	Tons	65,000	4,020,721
Oil refining	437	1,494,474	1,887,890,000	Bbl.	770	1,453,675
Gasoline	—	—[2]	791,325,000	Bbl.	357	791,325
Wood pulp:						
Sulfate	226	415,938[2]	5,356,710	Tons	64,000	342,829
Sulfite			2,795,960	Tons	60,000	167,758
Soda			491,580	Tons	85,000	41,784
Groundwood			2,049,814	Tons	5,000	10,249
Paper	665	1,050,108[2]	10,646,833	Tons	39,000	415,226
Paperboard			9,186,810	Tons	15,000	137,802
Coke	167	—[2]	79,146,000	Tons	3,600	284,493
Beer	440	808,946	88,027,000	Bbl.	470	41,373
Whiskey	226	472,357	246,443,000	Gal.	80	21,155
Milk, cream, and butter[3]	—	—[2]	72,440,000,000	Lb.	0.11–0.25	12,286
Canning and preserving[4,5]	2,265	609,939	391,546,000	Cases	7.5–250	8,520+
Manufactured ice	3,423	226,584	36,100,000	Tons	243.85	8,802
Soft drinks	5,618	421,000	927,700,000	Cases	2.5	6,250
Woolens and worsted fabrics	495	599,534	464,563,000	Lb.	70	3,252
Wool scouring	74	54,166	210,172,000	Lb.	1.26	2,648
Tanning	561	403,783	238,731,000	Lb.	8	1,910
Soap	249	450,721	4,138,001,000	Lb.	0.25	1,034
Meat packing hogs	2,153	—[2]	51,678,047	Hogs	11	568
Cane sugar[7]	25	98,112	358,000	Tons	1,000	358
Rayon, all types	38	447,900	746,900,000	Lb.	0.16	119

[1] Data from 1947 U. S. census of manufactures.

[2] Value added by manufacture not given on same basis as production on which water consumption is based.

[3] Based on U. S. Dept. of Agriculture figures for creamery butter, liquid milk, and cream sold in communities; no other milk products subject to water consumption estimates.

[4] Excluding fish.

[5] Estimate of 8,500 m.g. includes water used in processing only 14 fruits and vegetables (177,321,000 cases) for which consumption factors are available. Total water used by this group is probably two or three times as high.

[6] Includes filling cans and pulling cores.

[7] Includes refining only.

to replace evaporation losses and blowdown losses for cooling tower operation.

In the absence of cooling towers, the large volumes of water needed for cooling must be obtained from fresh surface-water or salt-water sources. Where the surface-water supply is limited, the effects of the withdrawal and return of cooling water to lakes and rivers may materially increase the temperature and thereby degrade the value of the water for other uses. The Mahoning River furnishes a good illustration, the river water temperature consistently averaging 20° F. above the air temperature throughout the year. This is caused by constant use and re-use of this supply for cooling over a limited section of the river's course.

In addition to the cooling water needs for electric generating stations, enormous quantities of water are required for cooling during processing of manufactured products. There are no complete data from which the total volume of water used for cooling can be calculated or estimated.

Usually, the volume of water actually entering into a finished marketable

product is a small portion of the total quantity consumed. A canning company using as much as 2,200 m.g. of water per year estimates that less than 6 per cent of this quantity, or 132 m.g., actually contacts the processed food in such manner that it could become part of the food product. A much larger percentage of the total volume of water used does come in contact with the food during such preparatory processes as washing and soaking. Water to cool cans must be of good chemical quality and sterile to safeguard the flavor of the product and avoid contamination.

Economic Significance

In Table II is shown the value added by manufacture by a selected group of industries which are notably large water consumers. The term "value added by manufacture" is the difference between the cost of the finished products and raw materials, and is used by the U. S. Department of Commerce as a true index of production by individual industries. It will be seen that these industries, to which large water supplies are vital, account for an imposing fraction of the total of $74,000,000,000 for all industries. The data are from the 1947 "Census of Manufactures" (2).

TABLE II.—Value Added by Manufacture in a Selected Group of Industries Using Large Amounts of Water[1]

Industry	Value Added ($1,000)
Chemicals	$ 5,365,201
Textiles	5,340,876
Steel	2,659,250
Petroleum refining	1,494,474
Rubber and rubber products	1,302,863
Paper and board	1,050,108
Meat packing	976,995
Canning, preserving, and freezing	916,621
Brewing	808,946
Dairy products	595,108
Whiskey	472,357
Soap and glycerin	450,721
Rayon manufacture	447,900
Paper pulp	415,938
Tanning and finishing	403,783
Manufactured ice	226,584
Total	$22,927,725
Grand Total, all industries	$74,425,825

[1] From 1947 U.S. Census of Manufactures.

TABLE III.—Gallons of Water Consumed for Each Dollar of Value Added by Manufacture

Industry	Water Consumed (gal./$1.00 value added)
Steel	1,400
Paper pulp	1,352
Oil refining	973
Paper and board	527
Beer	51
Wool scouring	49
Whiskey	45
Soft drinks	15
Woolen and worsted fabrics	5.4
Tanning	4.7
Rayon	3.6

A complete catalogue of water consumption by the many units in each industry would be a hopelessly long and difficult task, but there are statistics available from which fairly good estimates can be made. The "Census of Manufactures" referred to above includes not only the dollar volume, payroll data, etc., but also production in units appropriate to the industry. Experts in the field of water supply and industrial waste have established rates of water consumption per unit of production for most of the industries (3) (4). These two sources of information have been combined to prepare the estimate of water consumed by various industries for the year 1947 (Table I).

The total of Table I accounts for nearly 7,800,000 m.g. per year, or water usage at the enormous rate of over 21,000 m.g.d.

The quantity of water required for each dollar of "value added by manufacture" varies widely in the industries for which data are available (Table III). Where 500 to 1,400 gal. of water are required for each dollar of value added, as in the first four

groups of Table III, cost of supply and treatment are of predominant importance. These industries must consider water supply to be a major limiting factor in their planning and development. On the other hand, in such industries as textiles, beverages, and others the relation of water consumption to value of products is so small that more elaborate treatment can be justified.

Plant Location and Underground Supply

The location of many industries has been dictated largely by the availability of an ample underground water supply. This is particularly important to industries using cold well water for critical cooling purposes. As an alternate to uniform, cold ground water, expensive refrigeration would be required.

Over-consumption of ground water in localized areas can, and has, caused water shortage, which results in economic difficulties. A typical example of such depletion occurred in Louisville, Ky., during World War II (5). This condition was brought about by the heavy construction of synthetic rubber industries in the area. The processes required large volumes of cold well water for cooling, and thereby materially increased the existing heavy draft serving other established industries in this section. The combined effect of water used was a rapid lowering of the ground-water table.

It should not be concluded that a decline of water level in a well field necessarily indicates an exhaustion of supply, as some lowering is, of course, necessary in order to obtain the maximum safe yield from any aquifer.

Similar conditions have been experienced elsewhere in this country. An additional illustration is the lowering of the ground-water table by the withdrawal of water from deep wells in the Texas City, Tex., area. In 1930, approximately 0.5 m.g.d. was withdrawn from the water-bearing aquifer; 15 years later the ground-water pumpage had increased to over 23 m.g.d. In 1945, measurements at one well 1,000 ft. deep showed that the water table had receded to 102 ft. below sea level; in another well 610 ft. deep, measurements revealed that the level had dropped to 165 ft. below the surface. This draw-down not only increased the salt content of the ground water, but also resulted in dewatering of the sands in this area. This condition has resulted in a subsidence of the land, in one section, at a rate of 2.4 in. per year. In some critical but limited sections of the area, the subsidence has actually amounted to 1.5 ft. The case cited is extreme. However, there are many other locations where actual lowering of the ground water has created critical conditions.

Warne (6) has drawn attention to "trouble spots" throughout the United States where heavy draft upon the water-bearing formations has resulted in the depletion of the underground water at a rapid rate. These areas include the Central Valley of California, the West Basin southwest of Los Angeles, the High Plains of Texas south of Amarillo, the Grand Prairie region of Arkansas, certain areas of Long Island, New York, and elsewhere.

Warne (7) has forcefully voiced the danger of underground water exhaustion in critical areas, as follows:

"The realization of adequate control over our ground waters should not be delayed indefinitely. The maintenance of the economy in areas dependent on ground water is hanging in the balance. Over short periods of time available reservoirs of ground water can be drawn down somewhat, without serious results. During years of unusually heavy precipitation, above-average replenishment of ground water may postpone the day of reckoning resulting from excessive withdrawals. But we would be shortsighted indeed if we failed to recognize that to protect the heritage that rightfully belongs to the next generation, long-range solutions to these problems must be

developed. The Department of the Interior will contribute to a broadened base for river basin and water resource planning in which proper account is taken of the potentialities and limitations of ground-water utilization as well as those of surface water."

Based on the above observation and conclusion, a constructive program for the conservation of ground water is suggested. This is as follows:

1. Scientific investigation of ground-water resources.
2. Wide dissemination of the resulting data and principles.
3. Formulation of sound legal means of effecting desirable ground-water control.

Factors Responsible for Water Shortages

Basically, the conditions responsible for water shortages to meet community requirements are:

1. Failure to provide for equalization of surface-water runoff.
2. Over-concentration of population and industries.
3. Withdrawal of water from underground aquifers in excess of natural recharge.
4. Water wastage.
5. Failure to use available salt water in place of fresh water.
6. Selection of plant sites without adequate evaluation of availability of water for existing or predictable future requirements.
7. Inadequate design and planning of water-consuming processing equipment.

Effect of Concentration

It was reported recently (8) that from 1890 to 1940 the population of Texas increased 287 per cent; during the same period the demand for water increased more than 7,000 per cent. Startling as is this increase, similar conditions, but of a lesser magnitude, have been experienced in many other communities. This is illustrated by the statistics reported in Table IV. Where ample surface water is available or where underground supplies are not pumped at a rate exceeding the natural recharge, such increased demands can be tolerated. Whether or not such increases in water requirements can continue to be satisfied, especially from underground water, depends on how intensely industries are concentrated. Meinzer (9) reported that:

"About 10,000 communities, with about 75,000,000 inhabitants (1930 census) have public waterworks, of which about 6,500 communities, with about 20,000,000 inhabitants, are supplied with ground water from wells. The total yielded by wells for public supplies is estimated at 2,000,000,000 gallons a day."

As noted previously, heavy withdrawal of underground water in some areas may be practiced without danger, but in other areas continued excessive pumping must, sooner or later, prove disastrous. In this connection, Guyton (1) has stated:

"The truth is that there is no such thing as a nation-wide depletion or shortage of ground water. Ground water is a replenishable resource and in most of the country there is still a lot to spare that percolates unused into streams and into the oceans or evaporates into the air.

TABLE IV.—Effect of Industrial Expansion on Water Consumption in Various Sections of the United States[1]

Location	Period	Est. Pop. Increase (%)	Water Consumption Increase (%)
Baltimore, Md.	1938–48	6.0	69[2]
Baton Rouge, La.	1937–45	6.0	78[2]
Detroit, Mich.	1932–45	4.3	47[2]
Galveston, Tex.	1931–43	23.0	74[3]
Houston, Tex.	1931–43	34.0	61[3]
Texas City, Tex.	1931–43	63.5	2,500[3]

[1] Between 1890 and 1940 the population of Texas increased 287 per cent and water consumption 7,000 per cent.
[2] Consumption of municipal supply only.
[3] Consumption of both municipal and private industrial supplies.

"There are, however, a good many places where problems have been created because users have attempted to take too much water from too small an area. As the storage has been used up, the supplies in these areas have been limited to the perennial recharge and shortages have occurred because the recharge is not sufficient to meet all demands. Some of these shortages cannot be met economically by importation of water, and curtailment of existing industrial and agricultural development is in prospect. . . .

"Instead of being faced with the national problem of reducing our groundwater use, the problem is, rather, one of distributing the use so that over-development of local areas can be eliminated or kept to a minimum and so that better advantage can be taken of the ground water that is now wasted by return to the atmosphere or through passing unused on its way to streams and thence to the sea."

Water Wastage

Much of the distress from declining water supplies could be greatly curtailed by reasonable economy and drastic control of water wastage. Millions of gallons of water now being wasted can be stopped by reasonable conservation. In all cases where conservation methods have been practiced, the cost of supervision and control has been fully compensated for by dollar savings (10).

The American people, individually and collectively, have become the most wasteful nation in the world. This habit is demonstrated by the use of both surface and underground waters. Our water wastage is strikingly illustrated by a comparison of the per capita consumption of water in cities in Europe and in this country. The average per capita water rate in ten European cities, including London, Paris, Vienna, Edinburgh, and Berlin, before World War II, was 39 g.p.c.d., while in the same number of cities in this country it was 155 g.p.c.d. In the latter group are New York, Philadelphia, Baltimore, Chicago, Detroit, and others.

The existing water shortage in New York City is in part added proof of extravagance and the urgent need for concerted effort to curtail water wastage. Water conservation by industries and all other groups will be reflected in savings which are commensurate with the effort made to avoid waste. Beyond the immediate financial return resulting from such action, there are the larger and more comprehensive benefits to be gained, such as the effect on the growth and development of communities and the over-all welfare of the inhabitants. Without adequate water, specific limitations are imposed which retard the growth of all civic and industrial expansion.

No program of water conservation can be formulated which will be applicable to all communities or industries because the specific requirements vary widely.

Value of Flood Control Measures

Flood control projects have been established primarily to avert disaster from flood waters, but there are many resulting contingent benefits. Although not fully realized, conservation of flood water has a far-reaching effect, not only in minimizing water shortages for industrial requirements, but also in improving water quality. By stream flow control, the effect of depreciation of water quality by industrial and sanitary wastes is reduced in accordance with the degree of regulation. One of the most direct benefits resulting from such regulation is the prevention of salt-water intrusion into tidal rivers. It is a well-known fact that salt-water penetration into many fresh-water streams results from insufficient river flows. During the severe drought of 1930 and 1931, the salt content in the Delaware River at Chester, Pa., rose to 1,860 p.p.m. This location is approximately 80 mi. upstream from the mouth of the river. Normally, the salt content of the river in this area is less than 25 p.p.m. Such

TABLE V.—Relation Between River Flow, Dissolved Solids, and Chlorides; Delaware River Near Chester, Pa.

Month	River Flow (c.f.s.)	Chlorides (p.p.m.)	Tot. Sol. (p.p.m.)
Oct., 1930	1,760	550	1,300
Nov., 1930	2,410	600	1,500
Dec., 1930	3,150	600	1,400
Jan., 1931	3,720	100	320
Feb., 1931	5,100	60	300
Mar., 1931	13,100	30	150
Oct., 1931	1,850	110	380
Nov., 1931	2,130	250	670
Dec., 1931	4,990	105	320
Jan., 1932	12,800	40	160
Feb., 1932	12,600	20	100
Apr., 1941	21,810	20	440
May, 1941	5,506	25	450
June, 1941	5,034	25	300
July, 1941	4,978	30	350
Aug., 1941	4,150	60	600
Sept., 1941	2,046	420	900
Oct., 1941	1,632	550	1,250
Nov., 1941	3,144	580	1,180
Dec., 1941	7,492	210	800
Jan., 1942	8,161	90	480
Feb., 1942	9,399	25	305
Mar., 1942	22,300	25	250

conditions are reflected directly in the cost of treatment of the supply.

In Table V is shown the relation between river-water hardness and river flow at Philadelphia. Such increase imposes a direct financial loss not only to industry, but also to the entire population. The cost of soap consumption alone, to compensate for the increased hardness of the water, is a sizable amount.

The foregoing examples are illustrative of numerous other financial losses directly traceable to fluctuating chemical quality of surface-water supplies, corrections for which can be greatly effected by control of runoff.

Substitution of Salt Water

Many of industry's water requirements can be adequately fulfilled by salt water where such supplies are available. To safely use brackish water, industrial equipment must be fabricated of material to resist the aggressiveness of the water. Many water shortages now existing in the seaboard area and in locations where underground salt water is available, could be minimized or completely corrected merely by the use of the available salt water. No plant in a water critical area should be designed to operate solely on fresh water when salt water is available. Obvious as is this water conservation measure, many seaboard plants use no salt water. The principal reason for failure to utilize such water is the increased cost of corrosion-resisting materials. Over an extended period of time the use of salt water for many purposes can usually be justified, regardless of higher capital investments involved.

Laws Relating to Conservation of Underground Waters

Many laws relating to some phases of the withdrawal of underground waters are on the statute books, but such regulations are either inadequate or not enforced in many critical areas. However, there is a gradual awakening with regard to the need for this type of important legislation. It is to be pointed out, that any program for the conservation of water resources which may be developed on a national scale requires meticulous investigation into the needs of the various states, or areas of the country, so that local requirements may be coordinated with the proposed national conservation policy.

Corrective Program

The water demanded for our expanding industries can and must be provided. The solution of the problem, involving as it does complex economic aspects, may only be found by an enlightened viewpoint reflected by industrial management and equitable, reasonable regulations. Such regulations must be imposed by mutual agreement and cooperative efforts among those affected and by constructive long-term

planning by municipal and state regulations. Within the last few years, aroused public concern over these deficiencies has prompted the assembly of much information on the subject. However, there are still many deficiencies. The data thus far compiled must be assembled and additional information collected before an accurate evaluation of the problem can be made and controlling measures established.

Studies in locations in which the water supply conditions are actually or potentially critical demonstrate the need for the inauguration of a program including:

1. An inventory of water requirements on a national basis coordinated with actual and potential water resources available, including both surface and ground waters. This survey should be both local and area-wise with respect to major river basins and geological formations.
2. Making available factual data regarding over-industrialization within critical, or potentially critical, water areas and the desirability of decentralization of industrial users of large volumes of water.
3. A study of the inter- and intrastate control and regulation of flood waters to provide present and future industrial water requirements, regardless of other benefits accruing from such facilities.
4. Publication of salt-water usage as a conservation measure.
5. Expanding the activities of the state and federal agencies handling critical underground-water resources problems.
6. Provide technical personnel for the U. S. Geological Survey and comparable state organizations, together with the necessary funds to effect more adequately utilization of the valuable services of these organizations.
7. Coordinate the activity of waste disposal regulation groups with those interested in resources.

Pollution Aspects as Affecting National Resources Policy

Stream pollution, and to a lesser extent the pollution of underground-water resources, recognizes no state boundaries. No single stream, or other body of water, poses a nationwide problem, with the exception of coastal waters and their navigable tributaries, over which the federal government has long exercised control under the Oil Pollution Act of 1924. The problems of stream and underground pollution are for the most part either intrastate or regional in their extent and can best be solved by compacts between the states in the affected area, as illustrated by the Ohio River compact involving seven states.

The primary responsibility for the control of stream and subsurface pollution rests with the states and their political subdivisions. Where the pollution does not cross state lines it should be controlled by adequate legislation in the state directly affected. Where pollution crosses state lines it can best be controlled by compacts of all affected states. State compacts on pollution matters should be self-controlled, but in many instances would profit from research, guidance, and approval at the federal level.

Individual states, or groups of states in a compact, should consider the respective availabilities and requirements for water in their particular area and develop regulations to yield the greatest over-all good. There is believed to be no over-all federal pattern to fit all streams, areas, or conditions. It is, however, believed that the individual states and compacts may well confer with and keep abreast of the federal thinking, research, and regulations affecting water resources, with particular reference to their contamination problems, and should in general avail

themselves of the benefits of the national pattern and experience.

The federal government, through its facilities for studying stream pollution and its control, and the knowledge gained thereby, should make available to the states, compacts, and political subdivisions thereof, the basic data in its possession, including information relative to the success in other areas. The execution of the suggestions of the federal agencies should, however, be left to those directly affected.

Pollution of Water Resources

Pollution of water resources can be considered under the following general heads:

1. That due to urban and industrial wastes.
2. That due to the wastes from the development of natural resources, such as coal and oil.
3. That existing in limited areas due to return flow of irrigation water.

Until comparatively recently, disposal of wastes by dilution in either rivers or coastal waters was universal. This practice, along with the great increase in population, resulted in more critical areas, in which conditions varied from gross nuisance to a growing unfitness of the water for the purposes for which it was being used, such as public water supply, recreation, etc. As a result, many localities adversely affected by their own pollution took steps to correct the situation by the construction of treatment works, but in many cases relieved their local situation by carrying the wastes to the downstream edge of the city and discharging to the watercourse there. Eventually, in many cases, this practice polluted entire rivers and resulted in state legislation, and in a few cases to state compacts, to cope with the increasing pollution.

The results of the local, state, and state compact efforts have in general been quite successful, so that with comparatively few exceptions the recovery of the water quality is under way. In some states more than 90 per cent of all urban and industrial wastes are receiving artificial treatment before discharge to the water courses.

Progress is illustrated by the Chicago experience, where prior to 1900 the Illinois River was the most important commercial fishing stream in the United States. Beginning in 1901 all Chicago sewage was diverted to the Illinois River through the 37-mi. sanitary district canal. In a few years, even with diversion up to 10,000 c.f.s. from Lake Michigan, the dissolved oxygen in the Illinois River water was so depleted that fish life was destroyed for 150 mi. downstream. In the last two decades Chicago has installed efficient sewage treatment facilities, the diversion from Lake Michigan has been reduced to 1,500 c.f.s., and river quality conditions so improved that a thriving fish life has returned upstream for 100 mi.

In this improvement of urban waste disposal, industries—sometimes independently and at other times aided by the expert staffs of the municipality—have instituted recovery systems, which have both reduced their wastes and effected economies. Practically all of this progress in urban and industrial waste disposal has been accomplished and paid for by the local communities and industries, although the federal government, through WPA and PWA, contributed loans and grants during the depression. This phase of pollution control needs no federal financial participation. It should be financed by those who produce the wastes and benefit from their disposal.

Oil Field Brines

Statement of the problem on oil field brine disposal is far simpler than any conceivable answer might be. Brine is produced along with oil, in most fields. In typical fields, from

2 to 4 bbl. of brine are produced with each barrel of oil.

Analysis of brines will show chlorides as high as 150,000 p.p.m. and upwards. A typical analysis of chloride content shows:

$CaCl_2$	29,900
$MgCl_2$	8,363
NaCl	131,735
KCl	2,153
NH_4Cl	123
Total	172,279 p.p.m.

Changes in the characteristics of the water resulting from oil brines pollution greatly affect their availability for domestic and industrial users. Taste- and odor-producing organisms are frequently encountered in oil producing areas without previous notice, causing great concern to the public using water. Also, water departments are frequently required to make extensive additions to plants and reservoirs to combat the changes in quality resulting from oil developments.

Present Method of Brine Disposal

New fields generally use subsurface disposal in previous formations. The average cost is about 3¢ per barrel operation of the system. Some fields have difficulty finding suitable pervious formations for subsurface disposal. A landowners case is pending in the Oklahoma Supreme Court governing the cost to an oil company for such disposal. The outcome will govern future increased use of subsurface disposal, or might cause abandoning such disposal until a more equitable means of settlement is found. Subsurface disposal is the best known method at this time.

Older fields generally resort to brine disposal on the surface. These are the chief offenders. Vast areas of underground water are polluted by brine disposal, due to surface disposal and defective well construction.

Many streams are polluted with brine. Alluvium waters in such streams run high in chlorides (8,000 p.p.m. and up). An example is the North Canadian River at Oklahoma City, Okla., where there are 355 producing wells. Tests of chlorides entering the stream range from 150,000 to 270,000 p.p.m. below the city after dilution by stream flow from sewage treatment plants (no flow from precipitation). At a distance of 100 mi. east of Oklahoma City chlorides range upward from 3,000 p.p.m.

In Oklahoma it is estimated there are 20,000 marginal oil wells. Production per well is low. Ownership is usually one or two wells to one owner-operator and the income is small. It is reported that these wells would be shut down if the owner was to be required to finance and install subsurface disposal.

This appears to be typical of the problems in most oil producing areas of the United States.

Need for Investigation and Research

Marginal oil well production appears to be one of the principal contributors to pollution. There is a need for gathering information and investigating the problem to determine the economic situation with respect to control of pollution from marginal well fields; to determine if the value of oil is more or less than the value of the water resources the oil wastes destroy for domestic and industrial uses. There should be research on the best disposal methods; research on solids from brine, for example. With salt removed from brines the solids left constitute perfect mineral fertilizer for land use. Some solids also have other values.

Abandoned Oil Wells

Better methods and enforcement of proper plugging of abandoned oil wells should be developed.

New Wells

Better methods of protecting underground-water pollution by new wells should be developed and enforced.

Coal Processing

What has been said herein relating to pollution from oil brines applies in varying degrees to wastes from coal mining and washing, zinc and lead mining, smelting, oil refining, coking plants, and similar developments.

In many respects, pollution problems resulting from mineral developments are different from most other problems of water supply. These differences are inherent to the problem itself, as mineral deposits are very restricted in their occurrence and are localized by the particular character of local geology. This geographic restriction implies that the problems differ markedly from place to place and from one mineral product to another. These facts add to the difficulties of establishing uniform national practices.

Coal Preparation

Stream pollution from coal production falls into two general categories—that due to the acid formed following the opening up of the coal measures, and that resulting from the preparation of the coal itself. Practically all anthracite coal is prepared by the wet process, in which the coal is cleaned by many water sprays operating over the coal as it passes over the sizing screens and by water used to separate the coal from the gangue material, by one of numerous methods (such as jigs of various types; cones such as the Chance, Menzies, and heavy media using respectively, sand, water jets, and finely ground magnetite to float the coal off from the refuse; hydro separators of various types; and froth flotation in its various forms). Enormous quantities of water are used in the process. Inevitably, large quantities of fine coal and refuse particles are carried out by these waters, particularly in all of the processes except those recovering the finest sizes of coal.

In the past it was largely the practice of the anthracite industry to discard all sizes above No. 3 buckwheat (passing 3/32 in.) except in the case of companies using the smaller sizes for generating their own power. Progressively, and markedly so, after the Sanitary Water Board of Pennsylvania had begun its campaign for preventing silting of the streams, the companies have retained smaller and smaller sizes of coal, many of them now marketing No. 5 buckwheat and practically all of them retaining the finer solids in desilting works.

In the bituminous coal fields, the coal was prepared mainly by dry screening, with a certain amount of coal cleaned by an air wash and a relatively small amount by the wet process or by a combined air and water wash. More recently, a number of very large installations of preparation by the wet process have been placed in operation. When water wash was used, the water was very generally recirculated, hence resulted in comparatively little pollution except in times of "run out" for clean-up purposes or when accidents occurred.

The Pennsylvania Board requires that the effluent from all coal preparation plants, bituminous as well as anthracite, receive the equivalent of 1 hr. of efficient quiescent sedimentation under laboratory conditions and that it shall not contain more than 1,000 p.p.m. of solids. It has been found, in general, that a nominal retention of 3 hr. and an upward velocity in mechanically cleaned sedimentation devices of not over 3 to 3.5 ft. per hr., will provide the required degree of treatment.

Acid Mine Drainage

The second source of pollution is the acid drainage formed when the sulfur bodies in the coal, and particularly in the associated strata, break

down in the presence of moisture and air to form free sulfuric acid and iron sulfates, which later hydrolize to form additional free sulfuric acid and ferrous and ferric hydroxides, at times also associated with aluminum sulfate. The processes by which the pyrite, marcasite, or "sulfur balls" oxidize to their final forms of free sulfuric acid and the ferric hydroxides of various forms, are subject to some question and there are different schools of thought as to the role which bacteria play in these processes. The Sanitary Water Board of Pennsylvania has had a fellowship at Mellon Institute for four years, in an effort to solve not only the mechanism of acid formation, but also to devise means for minimizing, controlling, or preventing this formation.

The problem of acid mine drainage is so large and the need for a solution to it is so urgent that all agencies capable of cooperating in the work should do so in close cooperation. The role which the federal government can most effectively take in the matter is an active study, both by research in the laboratory and by experimentation with actual mines, in close coordination with the work of the states and all other agencies now engaged in this work and which can be effectively enlisted.

Backfilled open pit mines have in some cases in the past yielded practically no drainage after completion of the work; in other cases they have continued to discharge acid water. It is felt that the difference has been largely due to the methods of operating and backfilling of pits and it is hoped that experimental work may yield information which will help to greatly minimize acid mine drainage from strip mine operations. In addition, the Pennsylvania Board has under way some experiments on the treatment of acid mine drainage being carried out by Mellon Institute.

For deep mines, effective sealing where practicable, with trapped overflow to prevent building up of hydrostatic pressure, is at present the best known method for reducing or, in some cases, eliminating the production of acid mine drainage where a sufficient time has elapsed to bring this about. Mine sealing is not a panacea, but in many cases is quite effective. For deep mines it is about the only method now available.

It is believed that, without assuming any attitude of direction, the federal government, through its Bureau of Mines and through the United States Public Health Service, if the latter can contribute to the work, could and probably should engage in an active attack on the problem in close coordination with the other agencies, as previously indicated. When satisfactory answers are found, there will probably be little need to be unduly concerned as to the method of enforcement, because the importance of removal measures will lead to reasonable enforcement through the self-interest of each state involved.

Pollution Control Procedure

In every area of varied topography and land and water use, there develops sooner or later a general pattern of water quality zones. This happens whether there is definite conscious planning by government agencies or whether matters are left to take their own course and whether conflicting interests adjust their differences by peaceful means or settle them in law courts. In a very general sense, the result is the same. In primitive catchment areas of little or no habitation and industry, streams remain largely in their natural state and quality of water is generally good. In the flat valley and plains areas, streams receive return drainage from irrigation and, at scattered locations, wastes from the sewerage systems of towns, mines, and industries. The quality of water in streams in this area is gen-

erally moderately polluted, although not uniformly so, but is usually still salvagable for most uses. Lastly, there are areas near the mouths of streams or near bays and harbors where wastes from cities and industries are concentrated, and pollution, of surface waters at least, renders water unfit for those uses requiring water of a high degree of purity.

Such a pattern has already developed in many of the states and the three zones can probably be delineated for each of the states, or for the country in general, by appropriate authorities.

Because such patterns always seem to take shape, many states have built their programs of control of water pollution upon a basis of planned zoning of streams according to major uses (and abuses) of water, and within each zone have established water quality standards designed to be consistent with those uses.

This method of regulation has certain very powerful advantages; it lets waste producing agencies and activities know very definitely where they stand, and it furnishes a simple basis for administration of a governmental control program.

On the other hand, the method has compelling objections, which cannot be lightly set aside. For example, the uses of waters within a zone are by no means uniform throughout the zone. Consider coastal or bay waters. In some areas such waters are inaccessible or, by reason of temperature or currents, unusable for any recreational purpose. In others, such waters may be used not only for swimming and bathing, but also for shellfish culture or for fluming and processing in fish canneries.

The effects of pollution are not uniformly dispersed throughout a zone from a source of pollution, but are restricted in geographical extent. Consequently, it is possible for highly exacting uses of water and sources of pollution of water to exist harmoniously in the same zone if properly related to each other geographically.

The successful program of water conservation must recognize that the need for economical waste disposal is just as exacting as the need for protection of water quality for beneficial uses, for lacking either there can be no sound development. Waste treatment nearly always consists of a combination of artificial treatment and natural purification, and economy in waste disposal requires that maximum emphasis be placed on the latter. This is only possible if the requirements in the disposal of any waste take into account the relative geographical locations of the point where the waste joins and the points of beneficial usage, so that full utilization may be had of the factors of natural purification in the intervening area.

Perhaps the greatest limitation to a zoning program is that it always tends to become fixed or permanent, and does not lend itself readily to a program of restoring lost water quality or upgrading a degraded area.

For these reasons a method of establishing the requirements of waste disposal in each region must be followed which will take into account at least the following key factors:

1. The total interest in a water pollution control program encompasses both economical waste disposal and preservation of the beneficial uses of water.

2. Requirements as to waste disposal must recognize the zone of influence of wastes with respect to bacterial, biochemical, physical, and chemical effects, and be only so severe as to protect beneficial use of water (including simple aesthetic enjoyment) within such zones of influence.

3. Account must be taken of both the present and future planned quality of a receiving water in setting requirements for disposal of a waste.

4. Requirements in all cases must be reached by a logical analysis of all of the pertinent factors of a given problem, rather than by simple reference to an arbitrary general rule, so that when examined judicially in court they will not be reversed.

5. The definition of "pollution" should be restricted to impairments of water quality which unreasonably affect such waters for beneficial use.

6. Standards for zone of influence of waste discharges must be defined by local, state, or regional authorities subject to review of the federal interests involved by the U. S. Public Health Service. It is to be expected that some beneficial uses of water will suffer from disposal of wastes. In order to insure that such detrimental effects are not "unreasonable," chemical, biological, and bacteriological standards should be specified for each zone of influence of such discharge of wastes.

7. Account must be taken of the fact that ground waters are of paramount importance in many locations, and that damage to ground waters is long-lasting if not permanent in nature, whereas surface waters recover rapidly when the source of pollution is removed. For this reason, risks of accidental pollution infrequent in occurrence that might be tolerated for surface waters cannot be tolerated where the quality of ground waters is at stake.

Summary on Water Pollution

1. Local governments, states, and state compacts are, in general, making good progress in the correction of pollution from urban and industrial sources. No financial participation by the federal government is indicated, except that necessary to support the U. S. Public Health Service in its research and educational work.

2. Pollution of water resources by the development of natural resources, such as oil, coal, zinc, and lead, as well as manufacturers of food products and chemicals, has been and remains excessive and in large measure unregulated in many localities. The industries involved have not responded adequately to their responsibilities and individual states have found it difficult to satisfactorily control the wastes within their boundaries.

3. Recognizing that rivers do not respect state lines, it is believed that studies, investigation, and research of pollution due to urban and industrial wastes and the production of oil, coal, and other mineral resources can be facilitated by legislation at the federal level. Such federal legislation should use to the greatest possible extent the existing state and interstate river basin compacts, local authorities, and industries and their facilities for the abatement of stream and ground-water pollution. Federal participation should be through guidance, rather than control of procedures.

4. Public Law No. 845 authorizes studies, investigation, and research in connection with stream pollution. It will be necessary for Congress to appropriate sufficient funds to carry out the intent of this law.

5. Research is needed on oil field brine. Under the authority of Public Law No. 845, it is recommended that a specific research project be approved with necessary appropriations, with the principal objectives of developing suitable methods of brine disposal and possible ways and means of utilizing the minerals in the brine.

6. In multiple-purpose projects, which may affect downstream public water supplies not included as a part of the project, there should be better coordination of the work of federal agencies. Many domestic and industrial water supplies are affected, due to the change in flow characteristics of the stream bringing about changes in mineral content and biological changes occurring in the reservoirs, with resulting greater algae growths. Also,

vegetation covered by waters of the new reservoir brings on unusual taste and odor problems. Because of these incidental problems, it is believed that the U. S. Public Health Service should participate with other federal agencies in the development of projects affecting public water supplies.

7. When no state or local agency is empowered to enforce the reduction of stream pollution within a state and such stream pollution can be shown to affect interstate waters adversely, legislation from a federal level should authorize and make provision to enforce corrections of the conditions, to the end that the pollution of the nation's streams and ground-water supplies may be effectively controlled.

Multiple-Purpose Projects Involving Public Water Supply

While up to the present time there have been but a few multiple-purpose projects in which public water supplies have been included, such projects may be more frequent in the future. Public water supply can usually afford higher costs than irrigation and it is proper for it to bear higher costs up to the maximum of that of the next available alternative.

The cost of the public water supply part of the project should be borne by those directly benefited rather than by the federal government. If, by reason of the local community's contribution for public water supply which it secures from the project, the remaining cost is within the proper cost-benefit ratio for irrigation alone, the entire project may be equitably built to the advantage of those benefited and without detriment to the federal taxpayers at large.

Such dual-purpose projects involving public water supply should not, however, be built wholly from federal funds without reimbursement by the local community benefited of at least the full cost of the work properly chargeable to water supply, plus such additional amount up to the value of the water supply as may be necessary to provide a proper cost-benefit ratio for the remaining part of the expenditure chargeable to irrigation.

Conclusions

1. The use of water resources for domestic and industrial purposes is believed to be the highest and best use. Without adequate water supply properly safeguarded against pollution, urban life cannot exist.

2. The use of water resources for domestic and industrial purposes is also the only universally distributed use. In this respect it is unlike irrigation or hydroelectric or flood detention, which are limited in area of development.

3. Although nation-wide in development, domestic and industrial water supply presents essentially local community problems. Of the 13,000 public water supply systems serving 85,000,000 people in the U. S. with approximately 15,000,000 gallons of water per day, nearly all are intrastate. Only a few have interstate problems and a very limited number are concerned with more than two states.

4. Urban or private industrial water supplies should accordingly be built and paid for by those using the service. The cost of water from public supplies, which is usually less than 2¢ per capita per day, is within the economic reach of all.

5. Since the domestic and industrial water supplies are of such prime importance it necessarily follows that pollution of water resources must be so controlled as to make it practicable to provide a water of satisfactory quality as well as adequate in quantity.

6. Pollution of water should be

regulated at the lowest governmental level adequate for the particular situation. Some will be wholly local, some at state level and some at state compact level. Federal jurisdiction and participation should be limited to the administration of existing laws; to research, investigation and guidance upon which sound state laws and local regulations may be based, with as much uniformity as is consistent under the variable conditions encountered.

7. On dual- or multi-purpose projects involving public water supply, the local community should pay its fair proportion of the cost and the project only then be carried forward if the remaining part of the cost to be provided from federal funds has a proper cost-benefit ratio.

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SUGGESTED STATE WATER POLLUTION CONTROL ACT

A "Suggested State Water Pollution Control Act," prepared by the Division of Water Pollution Control, U.S.P.H.S., is now available to agencies and individuals concerned with state legislation in pollution abatement. The suggested act has been developed in an attempt to promote uniformity in the various state laws dealing with the problem and its regulation.

An earlier draft of the suggested act was reviewed by more than 800 individuals and organizations representative of all the water users in the United States. Later, a committee of consultants, representing the state water pollution control authorities and state officials having a broad background in legislative procedure, evaluated the draft and the comments received. The present draft reflects in large measure the views of these individuals.

The Council of State Governments has endorsed the suggested act and recommends it to the states for favorable consideration.

Copies of the "Suggested State Water Pollution Control Act" are available on request to the Division of Water Pollution Control, Public Health Service, Federal Security Agency, Washington, D. C.

ADSORPTION OF *E. COLI* ON RIVER AND ESTUARINE SILTS *

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The adsorption of bacteria to various types of particulate matter has been studied by many authors. In this investigation the adsorption between *E. coli* and the particulate material of river and estuarine silts and the effect of brackish water on this attraction were examined. The term adsorption is used throughout this paper to describe the attraction between bacteria and various types of particulate matter, although the action may not be necessarily analogous to true adsorption.

In the early work on this problem, Kruger (1) found that the numbers of bacteria in water were reduced on the addition of coke, sand, clay, brick dust, magnesium oxide, and other powderlike substances. The adsorptive action was much greater in the case of substances with low specific gravity than with those of high specific gravity. According to Eisenberg (2), the degree of adsorption of bacteria depends on their lipoid contents, which are higher in the cells of the gram-positive bacteria than in those of gram-negative forms. However, there is no sharp dividing line between these two groups in regard to adsorptive capacity; some gram-positive species (*Corynebacterium diphtheriae*) are only faintly adsorbed, while some gram-negative species (*Serratia marcescens*) are well adsorbed. Using kaolin, Braafladt (3) noted a three-fold reduction in *E. coli* suspensions due to adsorption on the inert particulate material.

The phenomenon of adsorption of microorganisms on soil particles was first noted by Cutler (4), who observed the carry-down of protozoan suspensions by soil particles. He concluded that a surface relationship existed between the microorganisms and the soil particles. The term adsorption was first applied to the attraction of soil for bacteria by Chudiakow (5). He found that the adsorption of bacteria occurs in soil and that the percentage of adsorption varies for different species of bacteria.

Dianowa and Woroschilowa (6) noted that different soil fractions adsorbed bacteria to different extents, the finer fractions having a much greater adsorptive capacity than the coarser fractions. The decrease in biochemical activity on shaking a portion of soil with a culture of bacteria was much greater when the soil was made up mostly of very fine particles, such as silt and clay, than when the soil contained a larger proportion of sand. The higher adsorptive capacity of the finer soil fractions was confirmed by Minenkow (7).

Rubentschik, Roisin, and Bieljansky (8) in their extensive investigation of the adsorption of bacteria in salt lakes noted that in soil the degree of adsorption depends on the size of the soil particles. The smaller their size the higher is the percentage of adsorbed bacteria. But this holds true

* This investigation was completed in partial fulfillment of the requirements for the degree of Doctor of Philosophy and was carried out as part of the research program of the Baltimore Harbor Project of the Department of Sanitary Engineering, The Johns Hopkins University.

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only up to a certain limit, beyond which there is a sharp decline in the degree of adsorption. However, they reported that several investigators had previously observed that in the case of the very small particles adsorption takes place by the larger bacteria. Utilizing *Serratia marcescens* as their test organism, they found that the adsorption of bacteria by liman mud was dependent not on the concentration but on the absolute number of bacteria. There were differences in adsorption of living and dead bacteria, and for their test organism a zone of maximum adsorption was observed. Various sediments had different adsorptive capacities for the same species. It was also noted that bacteria adsorbed by mud might be partly desorbed.

In his studies on the adsorption of bacteria by soils, Peele (9) observed that bacteria may be attracted to and held on the surface of the soil particles, or the colloidal soil particles may be attracted to and held on the surface of the bacterial cells. The attraction of soil for bacteria was found to be markedly influenced by the base predominating in the soil-exchange complex, and it was suggested that this factor determines whether or not a given soil will adsorb a given species of bacteria. The soils saturated with Fe^{+++} or Al^{+++} adsorbed *Azobacter chroococcum* the most strongly and soils saturated with Li^{+}, Na^{+}, K^{+}, and NH_4^{+} adsorbed this species the least strongly.

Heavy inoculations of pure cultures of marine bacteria on being added to marine muds were found to be strongly adsorbed, as noted by Waksman and Vartiovaara (10). However, they found little or no adsorption on sand.

Rubentschik *et al.* (8) observed that great numbers of *E. coli* were constantly being carried into the salt lake from the sewage fields of Odessa. The rapid disappearance of *E. coli* was postulated on the basis of their being adsorbed by the ground sediments, which were being stirred up by the tides. It was concluded that adsorption plays an important part in the processes of self-purification of the water in the salt lake. Death due to other factors was ruled out, as this species was found to have a long survival in liman water.

Materials and Methods

Bacterial Culture

The bacterial culture used in the following experiments was isolated from a sample of water collected in Baltimore Harbor. The organism conformed to the IMVIC test for *E. coli* as described in Standard Methods (11). It was carried in stock culture on nutrient agar and stored in a refrigerator. When a bacterial suspension was needed for an experiment, the stock culture was used to inoculate a tube of brilliant-green bile broth, which was incubated for 24 hr. at 37° C. Two ml. of the broth culture was poured over an agar slant, the excess drained off, and the slant incubated for 24 hr. at 37° C. The slant was washed of the bacterial growth into a suitable dilution blank and from this suspension the inoculum of any concentration could be prepared. This procedure was extremely satisfactory in producing bacterial suspensions whose concentrations were remarkably consistent, and thus unnecessary numbers of serial dilutions were avoided in obtaining plates suitable for counting. It also permitted standardization on the bacterial numbers that were to be exposed to adsorbing surfaces. All counts were made on Difco nutrient agar after 24-hr. incubation at 37° C.

Silts

The silts used in this investigation were obtained from four sources. The one designated "Harbor" was obtained from Baltimore Harbor at the point where the Patapsco River flows into the harbor proper. A weighted coring tube with a glass liner was dropped to

the bottom and several cores were obtained in one location. These cores were extruded from the glass tubes and the top 2 in. of the 1-in. diameter cores were combined into a single sample. The silt designated "Shenandoah" was obtained from the Shenandoah River just below the junction of the north and south forks of this river. The sample was taken from the banks, where it had been deposited during a recent rise in the river. The silt designated "Rideout" was taken from the bottom of a small stream flowing into Chesapeake Bay just north of the Severn River. The silt designated "Chesapeake" was taken in Chesapeake Bay offshore from Sandy Point. The latter two silts were collected, as was the Harbor silt, by combining the top 2 in. of several cores into a common sample.

Silt Fractionation

All four silts were handled in the same manner. After air drying, they were resuspended in distilled water. No dispersal agent was used, but the samples were violently mixed. Any fraction (usually sand grains) which would not stay in suspension but settled immediately, was removed. The remaining material was considered the complete sample and a portion set aside.

Each silt was sorted by sedimentation into four particle size fractions, using a 32.5-cm. settling column at 20° C. The total supernatant, to within 0.5 cm. of the bottom, was removed by siphoning after each settling period. The settling times and corresponding particle sizes are indicated in Table I. The range of particle sizes represents the average dimensions of many particle shapes, settling at the rates described by Stokes Law (12). Each fraction was resuspended and settled several times to achieve maximum removal of particles of other size ranges.

TABLE I.—Settling Times and Corresponding Particle Sizes of Silts

Settling Time	Particle Diameter (mm.)
1 to 5 min.	0.078 to 0.035
5 to 30 min.	0.035 to 0.014
0.5 to 12 hr.	0.014 to 0.003
Not settled in 12 hr.	<0.003

Turbidity Measurement

The turbidity of the suspended silt was used to measure the concentration of particulate matter. A photoelectric colorimeter, employing 150-mm. Nessler tubes and a volume of approximately 100 ml., was used to measure turbidity. The instrument was standardized with a kaolin turbidity standard according to the procedure outlined in Standard Methods (11). The silts or silt fractions were concentrated at a sufficiently high turbidity so that any desired concentration could be prepared by diluting with distilled water.

It was recognized that the measurement of the concentration of suspended particles by the light transmitting property of the suspension would be dependent on the scattering and adsorption properties of the particular particle size and soil type. However, the rapidity with which suspensions of similar particle concentration could be prepared for comparative study outweighed the limitations of this technique.

In earlier investigations on bacterial adsorption, the concentration of adsorbing material, soils, or soil fractions was of the order of 0.2 to 0.5 g. per ml. In the experiments described herein the highest turbidity was usually 1,000 p.p.m. Without correcting for the specific gravity of the soil types, 0.2 to 0.5 g. per ml. is approximately 200,000 to 500,000 p.p.m. of turbidity. The range of turbidities examined in this investigation coincided with that usually encountered in natural waters.

The sea water employed in the different experiments was obtained from the Atlantic Ocean. Collected at Ocean City, Md., on a flood tide, the water was filtered through cotton and stored in glass carboys in the dark.

Concentrations of less than full sea water were prepared by dilution with distilled water, the exact chlorinity being determined by titration with silver nitrate.

For bacterial dilution water and for dilution of silts in comparison with sea water, a dilution water was prepared according to Standard Methods (11). This is a standard water used for diluting samples for B.O.D. determinations. The dilution water used in the experiments is referred to throughout this paper as "B.O.D. water."

Experimental Methods

Adsorption between bacteria and silts was determined as a function of the increased rate of sedimentation of the cells when mixed with silt suspensions and centrifuged. The decrease in cell concentration in the supernatant liquid was compared to a control, which contained no silt.

Silt fractions were prepared at twice the desired final turbidity; for example, 1,000 p.p.m. was used when the experimental value desired was 500 p.p.m. Similarly a 2X concentration of the final sea-water concentration was prepared. Thus, the silt and sea water when mixed together diluted each other to the desired concentration.

If the experiment included the addition of bacteria, the 2X concentration of silt and sea water was sterilized separately prior to mixing. One ml. of a bacterial suspension was added after combining the two 2X concentrations. When a non-saline water was used for dilution, the silt was similarly prepared in 2X concentration.

Standard 15-ml. centrifuge tubes were used. Silts, diluting waters, and the tubes were sterilized separately. To each centrifuge tube, equal volumes (5 ml. of 2X silt and dilution water and 1 ml. of bacterial suspension) were added and shaken. Controls were handled in the same manner, but contained no silt, 2X sea water being diluted with an equal volume of non-saline water. After a suitable contact period, the tubes were centrifuged for 1 min. at 1,728 r.p.m. in an angle centrifuge. One ml. of the supernatant liquid was then taken and diluted for plating.

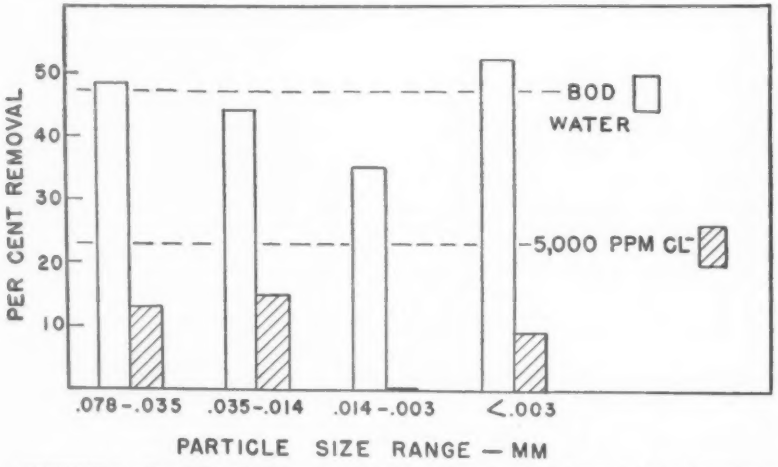

FIGURE 1.—Removal effectiveness of Harbor silt sorted into four particle size ranges and suspended in B.O.D. water and sea water (5,000 p.p.m. Cl). Dotted lines represent removal by unsorted silt.

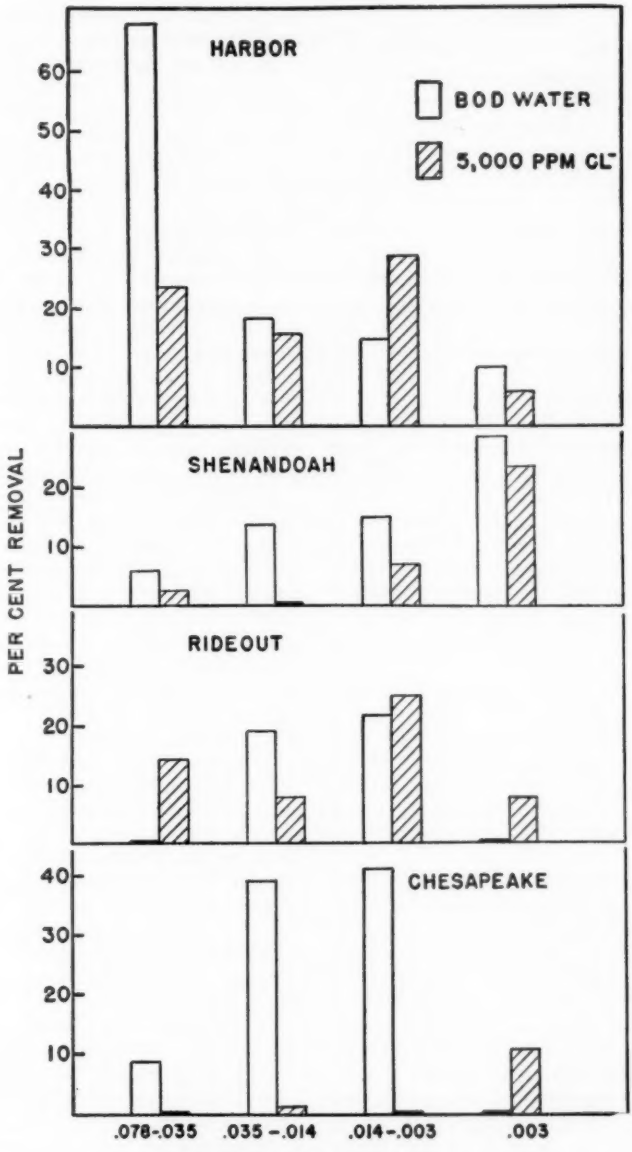

FIGURE 2.—Removal effectiveness of four silts sorted into four particle size ranges, suspended in B.O.D. water and sea water (5,000 p.p.m. Cl), and flocculated for 3 hr. before inoculation with bacteria.

Results

Employing the four particle size ranges of the Baltimore Harbor silt, a comparison was made of the effect of sea water (5,000 p.p.m. Cl^-) on their adsorptive capacity. As seen in Figure 1, the capacity of the silt to remove *E. coli* from the supernatant liquid was markedly greater in B.O.D. water than in sea water, whether in the non-sorted silt (dotted line) or in any of the four particle size ranges. It is also of interest to note that in both the B.O.D. and sea-water systems the minimum removal was in the particle size range of 0.014 to 0.003 mm.

Washed estuarine silts or river silts when mixed with sea water will "salt out." This behavior, which represents a marked increase in the rate of sedimentation, is due to the formation of a floc and is proportional to the concentration of sea water. In the silts examined in this investigation, the rate of sedimentation increased with increases in sea-water concentration up to a limit of 5,000 p.p.m. Cl^-, above which the rate of sedimentation was not markedly increased. To determine what effect floc formation might have on the entrapment of bacteria and the adsorptive capacity of silt, the following experiment was carried out using the four silts in the four particle size ranges.

The inoculated and mixed centrifuge tubes were allowed to stand for 3 hr. to permit floc formation prior to centrifuging. The silts were gently resuspended and then centrifuged.

As seen in Figure 2, the Harbor silt showed a maximum removal in the largest particle size fraction in B.O.D. water and considerably less in the same size range when mixed with sea water. In the size range of 0.035 to 0.014 mm. the removal in the B.O.D. and sea-water systems was about the same, whereas in the next smaller size the suspension in sea water increased the removal as compared with B.O.D. water. In the smallest particle range there was no appreciable difference between the two systems.

In contrast, the Shenandoah silt had an effectiveness of removal that increased with decreasing particle size. This was true in both B.O.D. and sea water, although in each of the particle size ranges the suspensions of silt in B.O.D. water had a greater removal than in sea water.

The behavior of Rideout silt indicated a variability in removal that was apparently characteristic of its particle sizes. In the largest particle size range there was no removal in B.O.D. water, whereas in sea water there was upward of 15 per cent removal. In both the sea-water and B.O.D.-water systems the optimum removal was found in the particle size range of 0.014 to 0.003 mm. The performance of the Chesapeake silt was of interest in that practically no removal in the sea-water system was found in the three largest particle sizes and only slightly more than 10 per cent in the smallest. This was in contrast to the B.O.D.-water system, which had effective removal in the three largest particle ranges, reaching a maximum in the size range of 0.014 to 0.003 mm. and then decreasing to no removal in the smallest size range.

The role of the silts in this experiment may indicate that if floc formation does play a significant part in the entrapment of bacteria, particular particle sizes may have optimum rates of formation. This behavior may be attributed to the specific cation adsorption found on the different particle sizes and the base exchange with the Na^+ of sea water.

To determine the effect of particle concentration on the adsorption of *E. coli*, the particle size range with maximum adsorptive capacity was used. The results of this experiment (Figure 3) re-emphasized the distinctiveness of each silt in its property of bacterial adsorption. The Harbor silt showed approximately a linear relationship between turbidity concentration and adsorption of bacteria in the largest par-

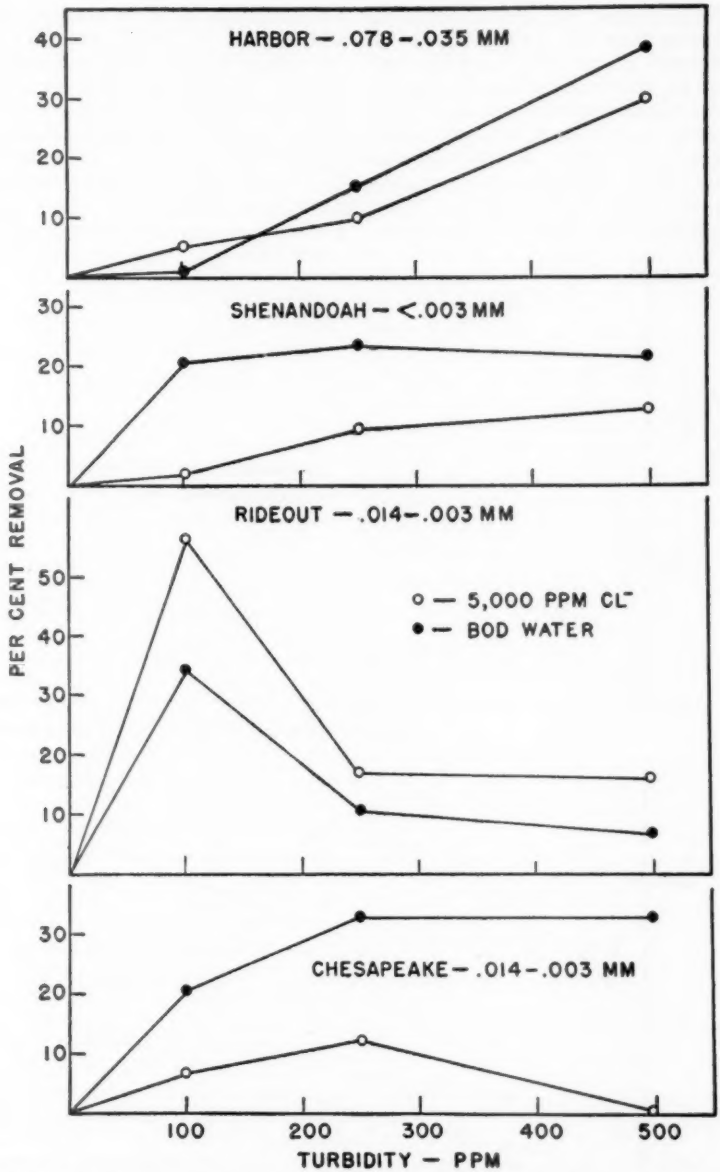

FIGURE 3.—Effect of silt particle concentration of selected sizes on removal of *E. coli*, by adsorption and centrifuging, from supernatant liquid.

ticle size range. The Shenandoah silt, in the smallest size range indicated a uniformity of adsorption and removal from the supernatant liquid, regardless of the particle concentration. This condition was particularly true in the B.O.D.-water system, whereas the sea-water system indicated an increasing removal with increasing turbidity. The Rideout silt was more effective in bacterial removal in the sea-water system than in the B.O.D.-water system throughout the silt concentrations examined. In addition, both water systems had a maximum effective removal at 100 p.p.m. A comparable peak was found in the sea-water system of the Chesapeake silt at 250 p.p.m., whereas the B.O.D. system of this silt reached a maximum removal at 250 p.p.m. and

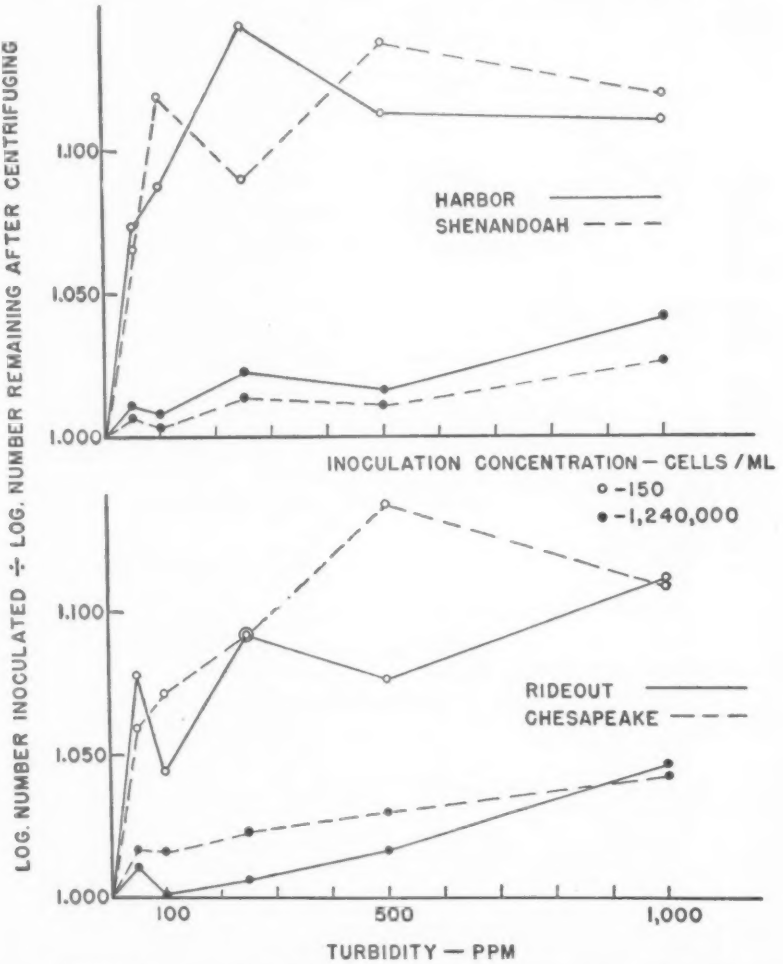

FIGURE 4.—Comparison of high and low bacterial concentrations on removal effectiveness of silts of varied concentrations.

retained this rate at higher turbidities.

The effect of bacterial concentration on the adsorptive capacity of similar particle sizes of four silts was examined in five dilutions in B.O.D. water. The same particle size range of each of the four silts (0.014 to 0.003 mm.) was prepared to give a final turbidity concentration series of 50, 100, 250, 500, and 1,000 p.p.m.

In the experiments described to this point, the bacterial concentrations used to inoculate the various silt systems were about 10,000 cells per ml. In this experiment inocula of *E. coli* were prepared so that each of the four silts in the entire turbidity series was mixed with bacterial dilutions producing concentrations of 150 cells per ml. and 1,240,000 cells per ml. Thus, the duplicate silt systems were inoculated with essentially a difference of 10^4 cells per ml.

To compare the effect of bacterial concentration, the ratio of the logarithm of the number inoculated to the logarithm of the number remaining in the supernatant liquid after centrifuging was plotted against turbidity (Figure 4). The ratio of concentrations was used as an indicator of effectiveness of removal; that is, the higher the ratio, the more effective the removal. The results of the experiment indicated a saturation effect of high bacterial numbers on the removal capacity of silts.

For all four silts, the efficiency of removal of low bacterial concentrations was at a nearly constant rate above 100 p.p.m. turbidity. However, the Rideout silt showed a slight trend toward more effective removal of the low bacterial concentrations with increasing turbidity, whereas the Chesapeake silt gave evidence of a removal peak at 500 p.p.m. Inoculated with heavy concentrations of bacteria, all four silts showed increased effectiveness of removal with increased turbidity.

In the experiments carried out in parallel for the B.O.D.-water and seawater systems, the latter was found to reduce generally the adsorptive capacity of the silt. This problem was examined with reference to the question as to whether sea water would cause desorption of bacterial cells after being adsorbed on a silt. The four complete silts, all particle sizes, were prepared in a B.O.D. suspension and also in water containing 1,000 and 5,000 p.p.m. Cl^-. The final turbidities were 500 p.p.m. Following a 10-min. contact period of the silt and water systems, the suspensions were inoculated with *E. coli* and contact of 10 min. additional allowed prior to centrifuging. The results of this phase of the experiment are given in Table II, exposure A. In all four silts the removal capacity decreased markedly with increasing chlorinity. The prior exposure to sea water of the silt reduced its adsorptive capacity.

The next phase of this experiment permitted the adsorption of *E. coli* on each silt in a B.O.D.-water system at

TABLE II.—Effect of Sea Water on Adsorption and Desorption of *E. coli* on Silts

Silt	Exposure[1]	Decrease of *E. coli*[2] (%)		
		B.O.D. Water	1,000 p.p.m. Cl^-	5,000 p.p.m. Cl^-
Harbor	A	37.0	15.3	13.4
	B	49.2	—	—
	C	54.0	37.4	26.1
Shenandoah	A	27.8	26.8	22.2
	B	33.0	—	—
	C	38.2	0	14.3
Rideout	A	59.0	33.6	0
	B	16.7	—	—
	C	21.4	16.7	19.2
Chesapeake	A	13.4	18.3	5.4
	B	16.5	—	—
	C	19.0	0	0

[1] A, 10-min. exposure of silt to sea water (except controls) before addition of *E. coli*; B, adsorption of *E. coli* in absence of sea water (turbidity 1,000 p.p.m.); C, sea water added to B to double volume and recentrifuged.

[2] In supernatant liquid after centrifugation of silts.

1,000 p.p.m. turbidity (Table II, exposure B). The suspensions were then diluted with equal volumes of B.O.D. water and sea water of 2,000 and 10,000 p.p.m. Cl^-, resuspended gently and recentrifuged (Table II, exposure C). The results showed conclusively that desorption of the adsorbed cells or separation of the particles and cells with consequent reduction in cell removal was effectively produced by the addition of sea water following the initial adsorption of the cells.

Discussion

The degree of adsorption of *E. coli* to the particulate matter found in river and estuarine silts is apparently characteristic of the particular silt. As in soil materials, the base predominating in the soil-exchange complex probably governs the adsorptive capacity of the silt. The low adsorptive capacity of the silts in the presence of the excess Na^+ of sea water supports this contention.

The consistently greater degree of removal of bacteria from the low concentrations of cells, particularly at the lower turbidities, may be explained by the fact that the number of particles necessary to increase effectively the density of bacterial cells by their adsorption to the cells is governed by the quantitative nature of the electrical charge. Thus, the charge difference between particle and bacteria is readily satisfied at low bacterial concentrations, where there are sufficient particles with charges of the opposite potential. At high bacterial concentrations the available silt particles with opposite charge are insufficient to meet completely the adsorptive capacity of the cells, or owing to bacterial clumping are less effective in increasing the rate of sedimentation. Thus, the change in density necessary for effective removal by sedimentation cannot be realized until adequate numbers of particles with the proper charge are present.

The adsorption of *E. coli* to silts may be of prime importance in determining their rate of sedimentation and distribution in natural waters. The desorptive effect of sea water may be of significance in determining the survival and distribution of *E. coli* in estuaries.

Conclusions

1. In the range of turbidities usually encountered in natural waters *E. coli* is adsorbed to the particulate matter.

2. The degree of adsorption is characteristic of the origin and particle sizes of the silt.

3. Adsorption to silt particles increases the rate of sedimentation of bacterial cells.

4. Diluted sea water increases the rate of flocculation of silts. However, silts suspended in sea water generally show a decreased capacity to adsorb. In some cases desorption of *E. coli* occurs.

Acknowledgment

The author acknowledges with deep appreciation the stimulating suggestions and continuous encouragement of Professor Charles E. Renn, director, Sanitary Engineering Laboratories, The Johns Hopkins University, during the course of this investigation.

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TREND SPREADING TOWARD STRONGER POLLUTION ABATEMENT MEASURES

Acceleration of a trend of recent years toward the enactment of new state legislation aimed at curbing pollution of rivers and other waters by industrial wastes and untreated sewage is indicated by a survey of developments reported from state capitals throughout the United States, according to a supplemental report in "From the State Capitals," a monthly analysis of legislative and regulatory trends, prepared by Bethune Jones, Red Bank, N. J.

Further progress under existing laws and interstate cooperation in attacking the problem also is being reported, with more stringent administration policies looming in a number of states.

States considering new legislation aimed at either establishing pollution control agencies or strengthening the powers of those already established include Colorado, Maryland, North Carolina, Texas, New Hampshire, West Virginia, Maine, and Tennessee. Tennessee will consider recommendations urging participation in the Ohio Valley Compact. Similar action with regard to the New England Compact will be asked in New Hampshire.

Major legislative developments in pollution control during 1950 included creation of new state water pollution control bodies in South Carolina and Kentucky. Several other states used existing legislation as a basis for compliance with tightened pollution control regulations. State Supreme Court rulings in at least two states paved the way for anti-pollution activity by holding that cities may issue general obligation bonds for construction of sewage disposal facilities without a vote of the people if the city is under court order to clean up pollution of public waters.

THE OPERATOR'S CORNER

CONDUCTED BY HERBERT P. ORLAND

PREAERATION TANK OPERATION AT AN ACTIVATED SLUDGE PLANT

BY JOHN S. WHITNEY

Superintendent, Sewage Treatment Plant, Dade County Port Authority, Miami, Fla.

The purpose of this paper is to offer some pertinant data on the merits of a preaeration (or flow-leveling) tank, particularly the noted performances of such a tank at an activated sludge sewage treatment plant for domestic wastes. Previous to the installation of the tank, the plant served only the installations of one airline at the International Airport in Miami, Fla. However, in 1948, it was decided that the discharge from all other installations on the 36th St. side of the airport, which at that time was being serviced by septic tanks, would be brought into the plant for treatment. This necessitated enlargement of the plant to handle the added volume of sewage to be treated.

It was at this time that the preaeration tank was installed at the head of the plant, as well as another aeration unit. It should be noted that no other units in the plant were enlarged when the plant was remodeled; that is, the primary tank, chlorine contact chamber, and digester capacities were not increased. The new preaeration tank is shown in Figure 1.

Before enlargement, the plant was handling an average flow of 0.05 m.g.d., but with great difficulty. Analytical results showed only a fair degree of treatment in the various units as to B.O.D. removals, pH removals, detention periods, shock loads, etc., especially at the primary basin. This was primarily due to the periodic unloading of the lift stations, creating undesirable conditions to exist at the primary basin by reason of the extreme variation in flow.

Flow Improvement

It will be noted that "flow-leveling tank" is another name used for the preaeration unit, because that is just how it functions. With the flow coming to the plant in shock loads and partially septic due to retention upstream in the lift stations, the primary tank was usually greatly overloaded during the working hours, resulting in very short detention times and low settleability, B.O.D. removals, etc. Past records show that the flow through the primary tank would vary within minutes or seconds; that is, a flow as high as 0.78 m.g.d. would go through, let's say at 9:00 A.M., and at 9:01 the flow was down to 0.001 m.g.d. This condition was prevalent at least 14 to 16 hr. per day.

It is needless to point out what this condition can do to the over-all treatment. The records show the B.O.D. of the raw sewage running as high, at times, as 582 p.p.m. In a number of tests on the primary unit under these shock loads the B.O.D. removals showed such results as: raw 477, primary 498; and raw 310, primary 350. By comparison, since the preaeration tank has been installed the highest

B.O.D. on one occasion was 650 p.p.m. for the raw, 145 p.p.m. for the primary effluent, which points out the desired effects of eliminating the shock loads via the new tank. In no instance since this tank has been in operation have we experienced anything but good removals and detention periods in the primary tank.

As regards the flow-leveling properties of the tank, average flows are now 0.10 m.g.d., with the flow chart invariably showing a maximum of 0.17 to 0.20 m.g.d. and a minimum running around 0.0 to 0.05 m.g.d. This indicates that the preaeration tank definitely has eliminated the various troubles present before the tank was installed.

Aerator Improvement

It may be well to say something about the D.O. content of the aerators. Before the preaeration tank was installed these values used to run very low (0.1 to 0.9 p.p.m.) on week days, and as high as 3.5 to 4.6 p.p.m. on week-ends. The low D.O. content caused all sorts of undesirable conditions in the over-all treatment, whereas the excessive amounts of D.O. were equally troublesome in other ways, resulting in hardly ever obtaining good results anywhere along the line.

By contrast, we have enjoyed for some time the following results on the various units, which in turn have resulted in a high degree of treatment throughout the plant. At the start, B.O.D. removals were about 15 per cent at the primary, and about 90 per cent over-all. Presently, B.O.D. removals at the primary average 35 per cent; over-all removals average 99 per cent. The pH has shown the same degree of drop through the pri-

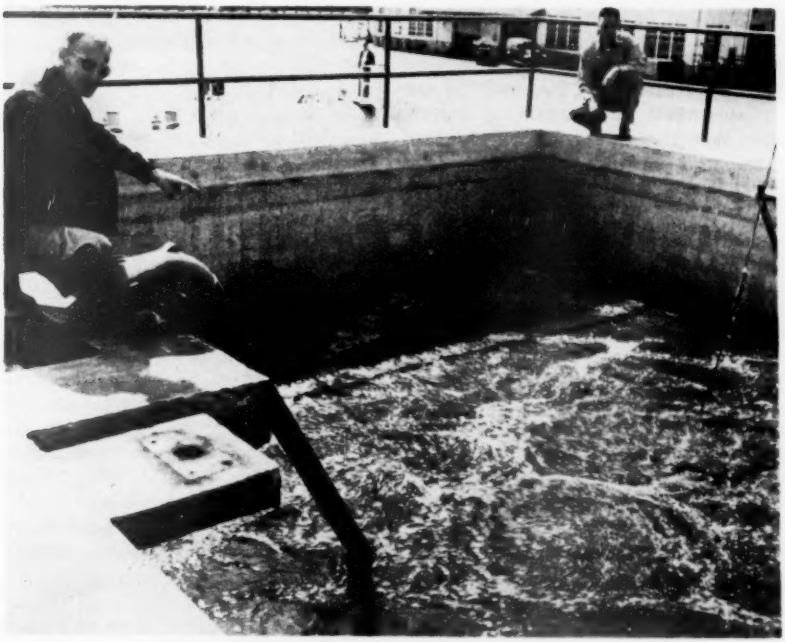


FIGURE 1.—Preaeration tank smooths out shock flows of septic sewage and increases dissolved oxygen content.

mary unit. It is noteworthy that the B.O.D. of the raw sewage coming into the plant from the lift stations is running about 150 to 200 p.p.m. and that the preaeration tank does remove some of the B.O.D. (about 10 to 20 per cent) from the raw sewage before it enters the primary unit. Of course, it also has been found that where the B.O.D. is low to begin with this reduction can be harmful, as it transforms an average sewage into a weak sewage. Obviously, this could be bad if the sewage continued to remain weak, but fortunately we have not had too much of this trouble. Nevertheless, it is well to bear in mind that a preaeration unit can do harm, as well as do good. In most cases, however, the oxidation that goes on in the tank is beneficial.

Pumping Rates

There no doubt are various methods of pumping used in transferring sewage from preaeration units to primary tanks. However, the method employed at this plant has been found to work well in maintaining a uniform flow over the 24-hr. period. The installation includes two electronically controlled sewage pumps, with the motor speeds controlled by the head of sewage in the preaeration tank. In this way, the additional head in the tank is compensated for by decreased motor speeds, maintaining a fairly accurate flow rate and increasing flow through the pumps gradually. Conversely, lowering of the tank level increases the motor speeds and decreases the flow rate slowly. The results are gratifying, as there are no longer any shock loads entering the plant.

Short-Circuiting Eliminated

To return to the primary unit for a a moment, the preaeration unit will afford a more uniform detention period throughout the 24 hr., as elimination of the shock loads by provision of uniform flow reduces the likelihood of short-circuiting through plant units. This type of trouble has been overcome not only in the primary tank, but also in the aerators. Before the preaeration tank was installed it was common for the heavy flows to go through the secondary units so quickly that the floc was carried right out into the final effluent—a good way to lose the flora, bacteria, etc., that are so necessary, especially in activated sludge treatment. Elimination of the short-circuiting has made it possible to control the solids content in the aerators a great deal better. Also, the clarification results are greatly improved and the number of coliform organisms in the effluent has been considerably reduced. As a result, the receiving stream at the outfall is now in good condition, whereas at one time the stream was in bad shape.

Conclusions

No claim is made that a preaeration tank will solve all the problems mentioned or that the one described herein has been the prime factor in all the good results noted. However, it can definitely be stated that with such a unit the plant operations can be handled in such a manner that the imposed criteria can usually be obtained. When the flow can be held back and taken as needed, or as the plant has been designed to handle it, the performance of the various units can be studied under the proper flow conditions. In this manner, one can determine detentions, removals, etc., which, when properly interpreted, will enable the use of proper control methods to turn out an effluent justifying the operator's pride.

TRICKLING FILTER FLY CONTROL

By Arnold M. Livingston

Chemical Insecticide Corp., Brooklyn, N. Y.

The *Psychoda* fly is considered to be a nuisance to residential areas surrounding trickling filter plants because these small flies penetrate through average size screening and crawl into the ears and nostrils of humans. The insect is particularly attracted to sewage filter beds, because they afford excellent housing and food (carbonaceous colloids), and to other areas where organic matter is in the process of decomposition. They are particularly harmful to newly painted surfaces and often require that windows and other areas be cleaned frequently.

In the past, attempts have been made to control the larvae and adults by flooding the filter beds. This method is somewhat unsatisfactory, due to the fact that when beds are flooded the sewage is not properly treated and must be by-passed temporarily into the streams, causing pollution. Also, some damage to the film occurs through chemical and bacterial deterioration. Certain chemicals that have been offered for use in controlling *Psychoda* often do material damage to the zoogleal film, which defeats the use of chemicals for this purpose, as the basic interest is in the treatment of sewage. Other methods of control have included application of insecticides by hand or mechanical sprays, and addition of DDT or BHC (benzene hexachloride) emulsions to the liquid sewage.

Several years of experience at the Ridgewood, N. J., plant had shown that none of these methods gave more than extremely short control periods. Although Hood (1) indicated that BHC was effective in 1948, it failed to give control in tests during 1949 (2).

New Control Chemical

As a result of a study of the problem, a new product, Chem-Larv,* was developed and tested. The main problem encountered in controlling *Psychoda* flies is in gaining access to their breeding area. The particular advantage of the new compound is that it dissolves in the liquid sewage, forming a true solution readily absorbed into the zoogleal film, which in reality is a mass of living organisms that convert colloidal food taken in from liquid sewage through a chemical reaction with enzymes into soluble food for both the living organisms and *Psychoda* flies. Since the majority of flies eventually develop from the larvae within the zoogleal film covering the media, it is important that the toxicant reach through this highly adsorptive and absorptive mass and kill the larvae and pupae by dispersion under, throughout, and on top of the film.

Different toxicants are prepared in a Chem-Larv base. By adding a toxicant to the liquid sewage it is not necessary to flood the filter beds or cause voluntary stream pollution by bypassing. Consequently, effective control is continually obtained while the sewage is being treated. With flooding, the problem may be alleviated a maximum of several days, after which time there is usually a severe re-infestation of flies. With the use of Chem-Larv, control periods up to one month after each application have been obtained.

It must be emphasized that the recommendations for the use of Chem-Larv must be closely followed. It

* Manufactured by Chemical Insecticide Corp., Brooklyn, N. Y.

reaches the breeding source of the *Psychoda* and suppresses future broods, but usually takes two to three days before the full effect is noticed. A good rule to follow is that a minimum of material should be used for maximum control.

The compound should be added to the settled sewage at the dosing tanks prior to the application of the sewage to the filter beds. By placing the material in the dosing tanks a more thorough dispersion of the toxicant throughout all liquid phases occurs. When the sewage is sprayed through nozzles over the beds, whether by fixed nozzles or revolving arms, there is a more even dispersion of the toxicant over all media. By gradually adding the chemical to the dosing tanks there is a longer contact period of the toxicant with the rocks and zoogleal film.

Earlier theories based on adding insecticide to the sewage assumed that the toxicant penetrated through the zoogleal film but did not kill the *Psy-*

TABLE I.—1950 Filter Fly Control Record for Ridgewood, N. J., Sewage Treatment Plant

Date (1950)	Treatment	Results
May 5	Flooded filter	——
May 9	Flooded filter	——
May 11	8.5 gal DDT (34% emulsion) to dosing tanks in 24 doses; 2.5-hr. application time	——
May 12	Flooded filter	Heavy harvest of larvae, pupae and adults
May 16	Flooded filter	——
May 19	Flooded filter	——
May 26	1 to 3 p.p.m. chlorine to dosing tanks in night Flooded bed from 11 A.M. on	Fly control no good ——
May 27–31	Continued chlorine tests	Flies not affected; filter performance poor; bacteria evidently seriously impaired
June 1	Break-point chlorine through dosing tanks Break-point chlorine plus DDT Break-point chlorine plus Nacconal (wetting agent)	No good No good No good
June 5–6	Break-point chlorine	No good
June 7	Flooded filter	——
June 13	Flooded filter	——
June 15	Flooded filter	——
June 16	Flooded filter	——
June 20	Flooded filter	——
June 22	Flooded filter	——
June 23	Flooded filter	——
June 26	Flooded filter	——
June 29	5 gal. Chem-Larv I to filter in 10 doses of 0.5 gal. each per 10,000 gal. (5 doses each side of dosing tank); 16.7 lb. per acre-foot of filter volume	Good control
July 16	——	Flies coming back
July 24	10 qt. Chem-Larv I in 4 doses of 2½ qt. each per 10,000 gal.; 8.5 lb. per acre-foot of filter volume	No good, concentration too low
Aug. 15	5 gal. Chem-Larv II in 10 doses of 0.5 gal. each per 10,000 gal.	No good
Aug. 26	5 gal. Chem-Larv I in 10 doses of 0.5 gal. each per 10,000 gal.	Good control
Oct. 3	5 gal. Chem-Larv I in 10 doses of 0.5 gal. each per 10,000 gal.	Good control

choda because they had developed a resistance to DDT and BHC. However, with the toxicant actually dissolved in the liquid sewage complete penetration of the zoogleal film is obtained. Since the larvae and adults use the film as a source of food and nourishment, the penetration of the film by Chem-Larv poisons their necessary food source, causing mass deaths. The good results initially obtained with ordinary insecticides in filter beds may have caused these flies to change their habitat. In order to survive they turned from zoogleal surface feeders to inner-film and under-film feeders. The larvae killed by Chem-Larv do not come off into the liquid stream, but remain on the rocks where they are killed, thus allowing bacteria and other organisms to digest the dead larvae.

In certain areas it may be advisable to use a mechanical applicator (such as a fog machine or mist blower) to augment the control procedure, particularly where infestations of *Psychoda* flies may be blown in from breeding areas. Mechanical applicators can effectively disperse insecticide sprays that will leave residual deposits on natural barriers such as trees, bushes, buildings, walls, etc.

1950 Tests

Experiments at the Ridgewood plant in 1950 showed good control of both *Psychoda albipunctatus* and *Psychoda alternata* by the new compound (see Table I). The dosage was arrived at by calculating the bed volume, in acre-feet, with relation to the volumetric flow per 24-hr. period. The effectiveness of the dosage (5 gal. added to 100,000 gal. of sewage) was noted by the great number of dead larvae found in and under the zoogleal film on the media.

The dosage was based on the use of 1⅔ gal. (16⅔ lb.) of toxicant (Chem-Larv) per acre-foot, which compares favorably in cost with earlier experiments, in which the applied dosage went as high as 25 to 30 lb. of toxicant (DDT or BHC), per acre-foot with little results. At the dosage mentioned (approximately 1 p.p.m. of the 24-hr. flow), control at Ridgewood lasted three to four weeks. Reduction of the dosage to half the amount (July 24 test) gave inadequate residual control because of insufficient toxicant deposited on the rock surfaces.

In a similar test at Worcester, Mass., which is a high-rate filter installation with revolving distributors, an initial application of 3.84 lb. of Chem-Larv per acre-foot was effective for only seven to ten days. With the high-rate filter it theoretically should be possible to use less toxicant and still obtain approximately the same results as at Ridgewood. However, the Worcester dosage was too low to give optimum results at minimum cost. A second application about a month later doubling the dosage of Chem-Larv gave the same results. Both treatments were applied during a 1-hr. period. Extension of the dosing time to 2-hr. may improve the results, although the Worcester sewage, which contains a large volume of highly acid industrial waste, may necessitate more frequent dosing with lower concentrations of the chemical.

Application and Dosage

A recommended procedure for applying the new compound is to add it to the sewage flow at the filter dosing tank or influent line in such a way that it will be thoroughly mixed before the siphon or distributor operates. Initial applications indicated by tests to date for low-rate and high-rate filters are, respectively, 1⅔ gal. (16.7 lb.) and ⅞ gal. (8.8 lb.) per acre-foot. Seemingly, the toxicant is most effective if dosage of the entire amount is made to the bed during about a 2-hr. period. The normal resting time between sewage dosing apparently pro-

vides sufficient contact time for the toxicant to penetrate the filter slime growth, although two or three days may be required for the full effect to be realized.

Acknowledgment

Acknowledgment is made to John W. Hood, superintendent, for permission to use data pertaining to the 1950 tests at the Ridgewood, N. J., plant.

References

1. Hood, J. W., "How to Control Psychoda Flies in Sewage Treatment Plants." *Amer. City*, **64**, No. 5 (May, 1949).
2. Hood, J. W., "Annual Report, Ridgewood (N. J.) Sewage Treatment Plant." (1949).

THE DAILY LOG

New Britain, Conn.

By John R. Szymanski, *Superintendent*

December 1—A nice wintry day. Grit problem becoming a nuisance. Like the Ancient Mariner with his "Water, water everywhere!", our men are crying, "Grit, grit all over; not a spoonful of sludge without grit," and the sludge pumps are laboring heavily because of the grit content in the raw sludge.

December 2—Snappy snow storm all day. Having our own snow plow attachments for the heavy dump truck keeps our roads, etc., wide open. No more isolation because of snow storms.

A check of the sludge incinerator from hearth No. 1 through hearth No. 8 shows the following: No. 1 hearth, one arm dragging slightly and one tooth missing; No. 2, insulation off one arm; No. 3, all rabble teeth badly burned; No. 4, one tooth missing; No. 5, one loose brick near burner box; No. 6, burner box brick work beginning to give; Nos. 7 and 8, O.K. Did not shut incinerator down after this inspection, feeling it was still in satisfactory condition to continue operating.

December 3—Accident day! After checking outside primary tanks, one operator tried to short-cut back to the building and slipped. An old army man, who couldn't swim, but fortunately another employee was around to pull him out of the tank. Haste makes waste to the extent of two cracked ribs, loss of eyeglasses, and loss of 48 man-hours. All this happened on the day shift.

Two hours after the evening crew began, the shift laborer, while shoveling snow off the final tanks, slipped into a sludge well—results: three cracked ribs and loss of 56 man-hours.

All this after 800 lb. of calcium chloride has been spread around to prevent slippery conditions!

December 5—Plant safety inspection by the superintendent and assistant superintendent for the purpose of checking, inspecting and condemning as much as necessary for the safety of the employees. A notable exception—while checking a 6-ft. by 10-ft. iron grating over the manual bar screen channel, I was doubtful as to its security, so, to be sure, while holding on to a convenient valve stem jumped on it with all 210 lb. The grate had a weak spot; both grate and jumper ended up in the channel knee deep in septic sludge—results: a scare, wet and smelly clothes, and new gratings all over the plant.

December 7—Grit still causing operating difficulties. Heavy snow fall. The primary sludge hopper valves (bronze screw stems) are completely

threadless, so arrangements were made with a local machine shop to make new ones in a hurry. This is an economically good idea, as the valves are otherwise in good condition. Basically, the cause of the wear is fine abrasive grit.

All cables on the freight elevator were replaced as per orders of the State Labor Department.

December 15—Had all main floor window frames painted aluminum; excellent results in reflected brightness on operating floor. Now painting all plant doors with aluminum.

Heavy accumulations of rags again are being found in the hoppers of the sludge tanks, so have decided to renew the struggle with the triturator.

Final effluent improving, even though the flow is exceptionally way above rated capacity.

December 18—Dismantled the triturator completely and wrote to the manufacturer for advice and help regarding satisfactory operation of the unit. The cutting teeth furnished did not give more than 10 days' of satisfactory cutting.

December 21—Making extensive check on fuel oil deliveries.

Representatives of Chemical Corporation of Springfield, Mass., visited the plant to suggest that we change from using anhydrous ferric chloride to the use of liquid ferric chloride, with indicated savings in operating costs.

December 22—Laboratory effused with the aroma of herring and onion. It seems the night laborer was unaware of the Christmas party refreshments, and in his zeal to clean knocked over two quart jars of pickled herring, strewing it over the laboratory floor.

December 23—Minimum of operating—just the necessities. The annual Christmas party for plant employees was held in the front office and the laboratory with Christmas carols, good cheer, and good will aplenty. (Coke machine profits paid for the entire party.)

December 25—Christmas Day bulletin at the plant read as follows:

1. Merry Christmas to all.
2. Normal operating routine on all shifts.

December 26—The chain on the bar screen let go. After checking, decided to replace all chain; wear due to grit situation. New sprockets were installed on the mechanical bar screen, as the worn chains had chewed up the old ones.

January 1—Happy and eventful New Year! It rained all day, and the plant flow was directly affected with resulting sand getting in somewhere—in a supposedly separate sewer system!

January 4—Sludge pump troubles—one cylinder and piston cracked. The broken parts had to be discarded and replaced with new units.

Annual inventory taken of every item belonging to the Commission—this is a good practice.

January 5—One of the laborers received an eye burn from ferric chloride. Questioning divulged that safety glasses were not worn. We did not call down the laborer for his negligence, but we did emphatically expound supervisory advice to the operator in charge at the time of the accident.

January 11—The superintendent and assistant superintendent of the Middletown, Conn., sewage treatment plant visited us today. It seems they are having difficulties in obtaining necessary chain for the sludge collectors—the old story of retarded delivery. Our stock pile did not have the proper size to help.

A representative of the Carboloy Company visited the plant and conferred regarding triturator teeth. After a detailed inspection, it was decided to tip the old teeth with carboloy material and then operate the unit to determine the results.

The entire Sewage Disposal Commission inspected the plant and facilities this afternoon. Everything doing

what it should be doing. After the inspection we all drove to the Stanley Chemical Company in East Berlin to inspect a special centrifugal pump, which probably could be used for grit pumping.

January 13—A terrific ice storm hit the area during the night and early morning hours. Everybody slid to work this morning.

January 17—Conferred with representatives of the Metropolitan District of Hartford on the matter of furnishing sewer and sewage treatment services to a certain section of the Town of Newington.

Painted the chlorinator aluminum. We are carrying out a paint schedule with aluminum paint in order to see how effective this scheme is going to be.

Also overhauled the entire lime solution feeder and replaced all worn parts.

January 23—Plumbers' paradise attacked today. Began cleaning and painting the maze of piping in the plant basement and pipe gallery.

Continuing efforts to collect money from drunken driver who damaged plant fence last summer; it looks like a court case coming up.

January 24—A new safety program has been inaugurated at the plant. A rotating committee of two—that is, the assistant superintendent and one operator—will be required each month to turn in a comprehensive safety report, which in turn will be reviewed by the superintendent and acted upon where necessary. A complete report is to be presented to the Commission every two months.

February 3—Carboloy Co. representative at plant regarding tipping of triturator teeth. We have agreed to proceed with a trial run. The project looks like a worth-while venture.

February 5—Triturator in full operation and doing a splendid job. We will observe operations closely from now on.

February 8—The ferric chloride feeder is acting up. We have written the manufacturer regarding replacing the unit, but it seems that the model in question has been discarded. We have found it a very satisfactory unit—simple, positive, and accurate, with no fancy trim or remote controls about which to worry.

February 14—Plenty of snow during the past two days. The men are nursing sore backs from snow shoveling. Operations are satisfactory throughout.

We are not in a good mood today, being aggravated by equipment manufacturers who sub-contract work on an original order and then later are unable to furnish replacement parts because the sub-contractor has gone out of business!

February 21—One set of cross collectors in the No. 1 primary tank jumped the drive sprocket. It seems as though troubles of this sort happen only on the coldest, windiest, and stormiest days. Nevertheless, the tank was back in operation 6 hr. later.

February 22—Legal holiday—but not at a sewage treatment plant!

March 10—The past couple weeks have been busy ones. All oil burners were dismantled, cleaned, and replaced; much better operation resulted. Also, both lime pumps were overhauled and new shafts and impellers installed. The inclined sludge conveyor belt is showing the wear and tear of the past 12 years and needs replacing.

With such items always popping up, it's amazing how many people think a sewage treatment plant should run itself indefinitely on no funds!

CALIFORNIA EXPERIENCES WITH GARBAGE GRINDERS *

Mr. Green, Long Beach:—Long Beach has experienced some problems in the sewer system because of home garbage grinder installations. In particular, these problems are concerned with cleaning of sewer lines. Most lines have average flow conditions, but grease, eggshells, and bone residues collect in lines in a section of the city where many grinders are installed.

Keeno Fraschina, Superintendent, Richmond-Sunset Sewage Treatment Plant, San Francisco:—Limited experiments conducted in San Francisco over a two-week period show that if flow velocities are maintained at 2 ft. per sec. the ground materials will not settle out. Eggshells present the greatest problem. Solids were run into the experimental line and left to settle for 48 hr. Consolidation resulted, but all deposited material was removed when flushed with a velocity of 2 ft. per sec. Hot water used in grinders permits discharge of grease, which solidifies far down the line when cooled. Some grinders permit use of cold water only, which is the best arrangement.

Question:—Is anyone legislating against the use of home grinders?

Answer:—There is some published information on this. Actually, there are two or three cities that refuse to allow such installations, whereas others have financed city-wide installations.

Question:—How many communities represented here have ordinances affecting home grinder installations or controlling their use?

Answer:—(Show of hands indicated five.) Santa Maria has regulations against the use of home grinders. Jasper, Ind., has an ordinance which, in effect, forces their installation.

C. L. Wright, San Bruno:—One manufacturer has encouraged San Bruno to permit some installations. However, they were made in houses having flat house connections. The resulting troubles in the house lines have discouraged further installations.

Question:—What about the increased water flow necessary with home garbage grinders?

Answer:—There is only a small increase in water flow (about 2 per cent), but considerable increase in solids.

F. G. Nelson, The Dorr Co., Los Angeles:—The increased solids and volatile matter results in more gas production and poorer supernatant liquor. Thus, at Lansing, Mich., three times more gas was produced with garbage included than with domestic sewage alone. However, a poor supernatant liquor was obtained. In the Midwest the volatile solids content of garbage is about 90 per cent, whereas in domestic sewage it runs about 70 to 75 per cent. In California the volatile matter in the suspended solids runs about 85 per cent.

* Excerpts from Operators' Breakfast Discussion, 1950 Annual Convention, California Sewage Works Association; Long Beach, Calif.; May 3–6, 1950; as published in *Newsletter*, California Sewage Works Assn., **1**, 5 (Oct., 1950).

CORROSION GROUP PROPOSES STANDARDS FOR SANDBLAST CLEANING PRACTICES *

Present-day sandblasting specifications need an overhauling. Too many of them result in needlessly high surface preparation costs. Still others do not prepare steel surfaces adequately

* Reprinted from *Paint Progress*, **8**, 3, 11.

for paint, or are blindly followed without regard to the specific characteristics of the metal protective paint systems that will be used.

So concludes A. J. Liebman in a recent article published in the magazine *Corrosion*. Mr. Liebman is chairman of the Surface Preparation Committtee of the National Association of Corrosion Engineers.

Closer definition of blast finish classifications is needed to replace the all too common prescription of "blast the surface and prepare for paint application." Neither can surface be specified purely in terms of depth of anchor pattern.

Surface Classifications

Mr. Liebman's committee proposes to eliminate the confusion by having engineers write dry blast specifications according to three exactly defined surface condition classifications.

"*Condition No. 1* is the White Steel Surface Finish which covers the complete removal of all corrosion products, all mill scale, and the grey mill scale binder, thus exposing the white metal for a good connection for either the adhesive or the bonding type coating. Single nozzle sandblasting will produce from 75 to 140 sq. ft. per nozzle hour (5/16″ nozzle at 100 lb. pressure. It is suggested that nozzle distance from steel surface be 12″ to 18″).

"*Condition No. 2* is the Commercial Surface Finish which includes the complete removal of all corrosion products, as well as all tight and loose mill scale. It does not include the removal of the grey binder. A commercial blasting job will look rather streaky; however, it does produce a very excellent surface anchor for either the adhesive or the bonding type coatings. Preparation speed with sand, 240 to 450 sq. ft. per nozzle hour (5/16″ nozzle at 100 lb. pressure. It is suggested that nozzle distance from the steel be 18″ to 24″).

"*Condition No. 3* is the Sand Brush-Off Surface Finish which includes the complete removal of all corrosion products as well as all of the loose mill scale. It does not include the removal of the tight mill scale. However, the sand does produce on the tight mill scale an anchor pattern, which is found fully suitable for either an adhesive or bonding type coating. Preparation speed with 30 to 50 grit sand equals 650 to 1,000 sq. ft. per nozzle hour (5/16″ nozzle at 100 lb. pressure. It is suggested that nozzle distance from the steel surface be 20″ to 30″). Before applying coating, surface should be solvent cleaned."

Sand Consumption

Any of these three systems will produce an anchor pattern for good paint adhesion, according to Mr. Liebman. Another real gain, he continues, is that they can be held within understandable tolerances that can be checked by an inspector as well as met by the operator.

Investigations have indicated that the average sand discharge runs 20 lb. per min. with a new 5/16 in. nozzle, operating under 100-lb. pressure and using a 30- to 50-grit sand.

In the final analysis, engineers can choose paint systems for metal structures only after the expected service conditions have been fully studied and analyzed, the committee emphasizes:

"For instance, a product that must perform a lifetime of service without subjecting it to impact or high vibration stresses, will hold a coating as effectively on a surface that was prepared with the brush-off method, than the one that received a white steel preparation. However, if impact and other surface forces will produce undue stresses between metal and coating, nothing less than a commercial surface preparation should be selected. In some cases, the white steel surface will be necessary."

Paint Adhesion Factors

Mr. Liebman differentiates priming paints according to the forces that hold them to metal surfaces. He classifies as "adhesive" those coatings depending on forces that are largely molecular in character. A second basic group of coatings he terms "bonding" because the forces tending to anchor them are principally mechanical.

TIPS AND QUIPS

Cheap Leak Repair

A leak in the digester heating system at the Princeton, Ind., sewage treatment plant in January, 1950, seemed to indicate that draining of the digester and expensive repairs were called for. However, Frank Kimbrough, superintendent, applied his "household headaches" experience to the problem and consulted a local plumbing supply house.

As a result, he purchased a can of Boiler Solder Seal, partially drained the digester, mixed the preparation with some water, and poured it in the top of the digester coil system. This solved the heating system leak problem, as no trouble of this kind has been experienced since.

Although comparative costs are not available for the method used as against the coil repair method, it is obvious that a considerable savings was effected.

California *Newsletter*

A quarterly mimeographed *Newsletter* has replaced the annual Journal formerly published by the California Sewage Works Association. The costs of the *Newsletter*, which is expected to provide more frequent contact between members and allow them to participate in the activity of the Association throughout the year rather than only at the yearly convention, are to be borne by sponsor sewage works equipment manufacturers belonging to the Association. The first issue (October, 1950) contains 10 pages of highly readable material of interest to all classes of Association membership.

A hearty welcome to the new addition to our "family"!

Accident Costs

Accident "costs" are not "costs" at all, according to a recent issue of the National Safety Council's *News Letter*, which goes on to say:

> "A cost implies that we get something for our money. For the public money spent in accidents which have already happened, the public gets nothing. Money spent for prevention, on the other hand, has been proved beyond doubt to be an abundantly fruitful investment of public funds, as well as a debt we owe to the people whose time and toil we buy."

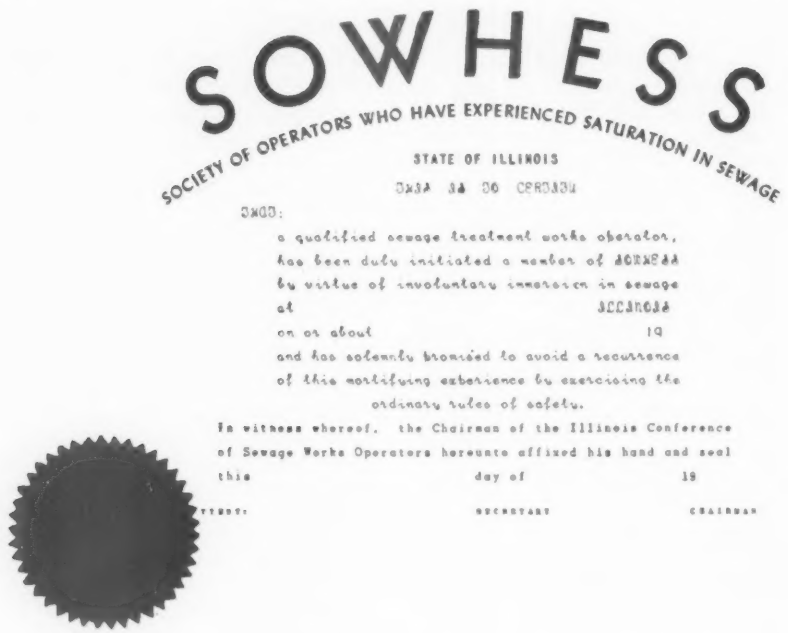
New Cutting Oil Preservative

A new odorless preservative for soluble-type cutting oils and coolants has been introduced by the West Disinfecting Co., Long Island City, N. Y. The product is claimed to increase the normal use of coolants from two or three days to a period of three weeks by inhibiting the growth of bacteria, stabilizing the emulsion, and preserving the lubricating qualities of the oil for its full life. A solution of only 1 gal. of the cutting oil additive in each 1,200 gal. of prepared soluble cutting oil is said to be effective.

Dunkings Continue

Although its recruiting activities are definitely of a negative type, the Illinois S.O.W.H.E.S.S. continues to receive additional involuntary members every so often. As a recent communique from Carl D. Gross, sanitary engineer with the Illinois Sanitary Water Board, puts it, "Progress cannot be stopped, and one more Illinois operator has been gathered into the fold, having literally fallen in."

New members are now presented with a proper certificate (reproduced herewith) designed and written by Richard S. Nelle, sanitary engineer with the Illinois State Dept. of Health, and complete with gold seal. The text, for those whose bifocals are unaccustomed to the pseudo-script of multigraph type, says:


SOWHESS
SOCIETY OF OPERATORS WHO HAVE EXPERIENCED SATURATION IN SEWAGE
STATE OF ILLINOIS
a qualified sewage treatment works operator,
has been duly initiated a member of
by virtue of involuntary immersion in sewage
at
on or about 19
and has solemnly promised to avoid a recurrence
of this mortifying experience by exercising the
ordinary rules of safety.
In witness whereof, the Chairman of the Illinois Conference
of Sewage Works Operators hereunto affixed his hand and seal
this day of 19
SECRETARY
CHAIRMAN

"This is to certify that _____, a qualified sewage treatment works operator, has been duly initiated a member of S.O.W.H.E.S.S. by virtue of involuntary immersion in sewage at _____, Illinois, on or about _____, 19___, and has solemnly promised to avoid a recurrence of this mortifying experience by exercising the ordinary rules of safety. In witness whereof, the Chairman of the Illinois Conference of Sewage Works Operators hereunto affixed his hand and seal this _____ day of _____, 19___."

Signatures of both the secretary and the chairman appear at the bottom.

Our informant says that the question of how best to acknowledge the degree and quality of submergence has tried the best minds of the profession at recent meetings of the Illinois Conference. However, there has been no unanimity of opinion on how best to indicate the nature of submergence. The South African system was deemed too complicated (see THIS JOURNAL, 22, 10, 1371; Oct., 1950). One suggestion offered was that immersion in sludge be considered as equivalent to immersion in twice that depth of sewage, so as to give credit for solids concentration.

Latest recipient of the "award" is Troy Kingery, operator at Griggsville, Ill., who slipped and fell 12 ft. into the final settling tank. Fortunately, he missed all walls, weirs, and baffles. Upon recovery from the "backbuster" he climbed out of the tank, rinsed himself with unused city water, and drove home for a series of showers, upon completion of which his wife is reported to have said that he "still smelled bad!"

Reclamation Project

The Southern California Edison Company is reported to be contemplating a water reclamation plant to provide cooling water for use in a new power plant. The plant, to be located near the Whittier Narrows in the lower

San Gabriel Valley, will process domestic sewage, thus conserving water resources in this area of water shortage.

Fine Feather Note

At the Operators' Breakfast discussion of the California Sewage Works Association 1950 Annual Meeting (May 3–6, 1950), T. J. Mays, superintendent, sewage treatment plant, Santa Maria, Calif., asked if chicken feathers would digest. His inquiry was logical, as he'd been having trouble with chicken feathers loading up the digester at the Santa Maria Airport plant.

The answer, of course, was that the feathers would not digest. However, not too much additional time had to be spent on the problem by local personnel, as the chicken killing plant closed the case very nicely—it simply moved out of town!

Paint Brush Tip

Aluminum foil wrapped around a paint brush immediately after use will keep the bristles pliable for several days.

Never Reached the Top

From the *Accident Prevention Bulletin* of the Royal Society for Prevention of Accidents (London) comes the following case history of an unusual accident.

A ladder fitted with non-skid rubber suction feet was being used by a man who was cleaning the walls of a lavatory. He was only about 2½ ft. from the bottom of the ladder when the rubber feet slipped. He fell awkwardly and fractured his thigh.

The ladder had slipped because the floor of the lavatory was wet and greasy from oil and grease brought in on the shoes of workmen. Use of a stepladder is recommended for such conditions. Also, because the floor was so dirty, it would have been wiser to have cleaned it before the walls.

Ohio Certification Examinations

Examinations for Ohio operators' certification in both water and sewage treatment for grades A, B, and C will be held Friday, April 27, 1951, in five Ohio cities.

Applications to take examinations must be made on forms furnished by the Ohio Department of Health and filed prior to March 17, 1951.

Information regarding certification may be obtained by writing G. A. Hall, Secretary, Advisory Board of Examiners, Ohio Department of Health, 301 Ohio Depts. Bldg., Columbus 15, Ohio.

Trappers Wanted

Hardly had the newspaper stories of the destruction of a mink farm in New Jersey by the gales of Thanksgiving week-end dried on the paper when an Urbana, Ill., boy began pestering his mother about the "rat" that kept coming out of the basement drain. With righteous indignation, mother investigated, but found the "rat" was actually a full-grown mink. What to do? Remembering the rabbit traps of early childhood, she fixed a string to the hinged metal drain cover. Then, when Mr. Mink came out into the basement again, the cover was closed beind him. Result: one mink trapped in the basement—and nobody foolhardy enough to catch the vicious little varmint for removal.

Well, that's one way of starting a mink coat!

Editorial

MATERIALS AND SUPPLIES PROCUREMENT

Developments since the 1950 Annual Meeting of the Federation have more than proved the good judgment of the Board of Control in acting at that time toward the prevention of materials procurement difficulties during the present trend into a wartime national economy. There is every indication now that some form of priorities control will be imposed on all civilian functions before the middle of this year.

Many of us do not relish recollections of the confused and uncertain materials procurement situation which provoked the sewage works industry during most of World War II. Fears of a recurrence brought about appointment by the Board of Control at Washington of a special Committee on Materials Allocation, charged with the duty of drafting a program by which the Federation might act to secure appropriate recognition of water pollution control requirements on the part of federal agencies delegated to the allocation of critical materials. The committee—composed of C. H. Young, chairman, with F. L. Flood, A. H. Wymore, W. A. Hardenbergh, and R. S. Rankin—drew up a strong resolution that opened the campaign in effective fashion.

In December, 1950, the approach to this problem was greatly strengthened by creation of a Water, Sewage, and Industrial Wastes Joint Committee on Critical Materials, made up of representatives of the Federation, the American Water Works Association, the American Public Health Association, and the Water and Sewage Works Manufacturers Association. This committee has compiled estimates of the quantities of critical materials needed in 1951 in the services represented, and obtained a hearing before National Production Authority Administrator W. H. Harrison on January 17.

Various essential public services and other civilian activities were assigned last October to existing federal departments and bureaus designated to function as "claimant agencies." Such claimant agency is intended to represent the service or activity in evaluating needs for materials and in making sure that essential requirements are met. Sewage works services were apparently assigned to the Housing and Home Finance Agency in the original order, although not specifically. This situation is presently unstable and subject to clarification. It is receiving major attention by the Joint Committee.

At this writing there is no priority rating system applicable to civilian industry needs. The National Production Authority (NPA) has established a Defense Order (D.O.) rating for military requirements, and has issued various "M-Orders" restricting the use of certain critical materials for civilian purposes.

In current cases of immediate hardship or emergency, an appeal may be made for relief assistance to the National Production Authority at any office of the U. S. Department of Commerce. Full circumstances of the case must be furnished for the information of the NPA Industry Division having responsibility for the products involved, i.e., machinery, chemicals, etc.

Special Chlorine Order

The increasing difficulty in recent years in securing chlorine for sewage works resulted in further action by the Board of Control at Washington in appointing a special Committee on Chlorine Supply, headed by L. F. Oeming, with L. L. Hedgepeth and L. H. Enslow. This group lost no time in making its objectives known in the chlorine industry, and considerable success has resulted.

On January 24 the NPA issued Order M-31 providing, among other things relating to chlorine distribution, that chlorine suppliers must fill orders for water and sewage treatment users at least to the same extent as in 1950. Where difficulty is encountered in chlorine procurement, or in the case of new users, a request for relief accompanied by full particulars should be filed with the National Production Authority, Chemicals Division, Department of Commerce, Washington, D. C. Copies of Order M-31 may be obtained from the same office.

W. H. W.

P.F.T.
CONTROLLED DIGESTION for the HAMPTON ROADS AREA, VIRGINIA

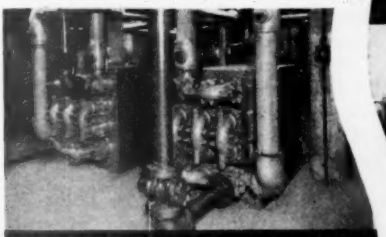
Lambert's Point Plant, Norfolk, Virginia—4 P.F.T. 80' Floating Covers, 2 P.F.T. No. 750 Digester Heaters and Heat Exchangers, 4 P.F.T. Supernatant Selectors and Gauges, 4 P.F.T. Floating Cover Gauge Boards, P.F.T. Gas Safety Equipment, Aldrich & Buck, Consulting Engineers, New York, N. Y.

The four new sewage treatment plants built to serve the communities in the Hampton Roads area all embody P.F.T. Controlled Digestion Equipment.

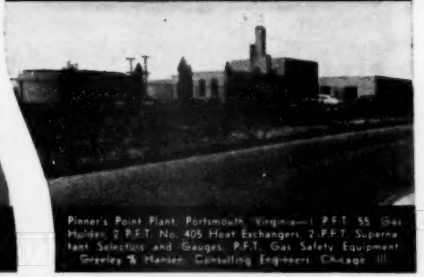
P.F.T. Floating Covers on digestion tanks, P.F.T. External Heating of Sewage Sludge undergoing digestion, P.F.T. Supernatant Liquor Selectors and P.F.T. Gas Safety Equipment are among the P.F.T. units insuring most efficient operation of these plants, pictured here.

This progressive program for waste treatment was carried on cooperatively by the Hampton Roads Sanitation District Commisson and the City of Portsmouth. The Pinner's Point Plant was built by the City of Portsmouth and the other three plants by the Hampton Roads Commission.

Army Base Sewage Plant, Norfolk, Virginia—2 P.F.T. 80' Floating Covers, 2 P.F.T. Supernatant Selectors and Gauges, P.F.T. Gas Safety Equipment, Aldrich & Buck, Consulting Engineers, New York, N. Y.



Boat Harbor Plant, Newport News, Virginia—2 P.F.T. No. 409 Heat Exchangers, 2 P.F.T. Supernatant Selectors and Gauges, P.F.T. Gas Safety Equipment, Greeley & Hansen, Consulting Engineers, Chicago, Ill.



Pinner's Point Plant, Portsmouth, Virginia—1 P.F.T. 55' Gas Holder, 2 P.F.T. No. 405 Heat Exchangers, 2 P.F.T. Supernatant Selectors and Gauges, P.F.T. Gas Safety Equipment, Greeley & Hansen, Consulting Engineers, Chicago, Ill.

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Proceedings of Member Associations

IOWA SEWAGE WORKS ASSOCIATION

The 32nd Annual Meeting of the Iowa Sewage Works Association was held at the Hotel Blackhawk, Davenport, Iowa, September 19–21, 1950. Members and guest registered for the meeting totaled 68.

After an address of welcome by Mayor A. R. Kroppach of Davenport, the meeting heard a paper on "Sewage Works Financing," by C. D. Mullineax, sanitary engineer, H. R. Green Engineering Co., Cedar Rapids, which evoked considerable interesting discussion from the floor. This was followed by a panel discussion on the "Role of Each in Stream Pollution," in which the panel members were:

"State Department of Health," by P. J. Houser, director, Division of Public Health Engineering, State Department of Health.

"Designing Engineer," by E. S. Boudinot, Brown Engineering Co., Des Moines.

"Operator," by Dean Larabee, sewage treatment plant operator, Waterloo.

"Wildlife," by a member of the Stream Pollution Committee, Izaak Walton League.

Programmed activities for the day were concluded with a social hour sponsored by the Water and Sewage Works Manufacturers' Association.

On September 20, the morning session opened with an "Operators' Breakfast and Over Coffee," at which a problem discussion for operators was led by W. H. Wisely, executive secretary FSIWA; D. Walker, Walker Process Equipment, Inc., Aurora, Ill.; and F. R. Martin, chemist, Marshalltown. This was followed by a paper on "Experiences and Operation with External Digester Heaters," by L. E. Langdon, Pacific Flush Tank Co., Chicago.

The afternoon session was devoted to a panel discussion on industrial wastes with the following panel members and topics:

"Meat," by J. Eckstein, Oscar Meyer Packing Co., Madison, Wis.

"Cannery," by M. Markland, Green Giant Co., Vinton, Iowa.

"Dairy," by G. Bernauer, public health engineer, Wisconsin State Health Department.

"Rendering," by F. R. Grant, Consumers Cooperative Assn., Kansas City, Mo.

Following a short business meeting, a social hour sponsored by the Water and Sewage Works Manufacturers' Association provided a relaxing interlude. At the Annual Banquet, the featured speakers were W. H. Wisely, executive secretary, FSIWA; State Representative Fred Schwingle; and P. J. Houser, director, Division of Public Health Engineering, Iowa Department of Health.

Papers presented at the session on September 21 included:

"Health and Safety," by Philip F. Morgan, assistant professor of sanitary engineering, Iowa University.

"Grit Chambers," by R. G. Dagg, Chain Belt Co.

"Legislation Review," by John Pray, superintendent of utilities, Fort Dodge.

"Extension Course Program," by W. E. Galligan, professor of sanitary engineering, Iowa State College.

(*Continued on page 66a*)

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"General Comments," by Charles Alexander, superintendent, Water and Sewage Depts., Ames.

The meeting was concluded by an inspection trip to the Davenport sewage treatment plant.

Officers elected to serve during 1950–51 were:

President: M. F. Neuzil, Iowa City.
Vice-President: M. L. Wickersham, Estherville.
Secretary-Treasurer: Leo Holtkamp, Webster City.

LEO HOLTKAMP,
Secretary-Treasurer

MISSOURI WATER AND SEWERAGE CONFERENCE

The 1950 Annual Meeting of the Missouri Water and Sewerage Conference was held at the Sheraton Hotel, St. Louis, Mo., Oct. 1–3, 1950, in conjunction with the Missouri Section, American Water Works Association. Registration at the meeting totaled 235.

The meeting opened on the evening of October 1 with a general discussion of the rules and regulations governing certification of waterworks operators, as proposed by a special committee.

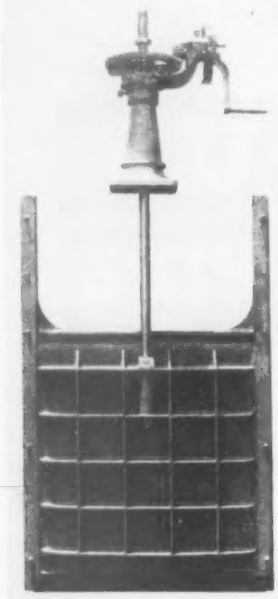
On October 2, papers presented at the morning joint session included:

"The Social Security Law and How It Affects Municipal and Public Utility Employees," by T. L. Gaukel, manager, Social Security Administration, St. Louis.

"Diesel Engines in Water and Sewage Plants," by G. Weidlich, vice-president, Western Machinery and Engine Co., St. Louis.

"Water and Sewage Plants in the St. Louis Area," by John B. Dean, engineer, St. Louis Water Division; Robert Lamberton, St. Louis County Health Dept.; and George D. Russell, consulting engineer, St. Louis.

(*Continued on page 68a*)



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The afternoon session was divided into concurrent water and sewage sections. At the sewage section, two papers—"Tips on Operation of Sewage Treatment Plants," by W. H. Wisely, executive secretary, FSIWA, and "Digester Operation," by L. E. Langdon, Pacific Flush Tank Co., Chicago—were presented. There then followed "Ask 'Em" session, at which a panel consisting of F. M. Veatch, consulting engineer, Kansas City; G. S. Russell, consulting engineer, St. Louis; L. E. Langdon; and W. Q. Kehr, Missouri State Board of Health, answered any and all questions.

At the Annual Banquet on the evening of October 2, the principal speaker was W. V. Weir, president, AWWA. Following the awarding of honors, the group was entertained by J. Moranville, Mississippi Lime Co., who performed feats of magic.

The morning session on October 3 was also divided into concurrent water and sewage sections. At the latter, papers presented were as follows:

"Sewage Pumping," by G. E. Hands, Burns and McDonnell Engineering Co., Kansas City.

"Industrial Wastes in Missouri," by K. Roberts and C. Summers, Missouri Division of Health.

"Plant Operating Records," by I. Knoebel, superintendent, sewage treatment plant, Belleville, Ill.

The afternoon was devoted to inspection trips to water, sewage, and industrial wastes treatment plants in the vicinity of St. Louis.

Officers elected for 1950–51 were:

Chairman: F. L. Thierfelder, Macon.
Vice-Chairman: R. F. Bishop, Booneville.
Secretary-Treasurer: W. A. Kramer, Jefferson City.
FSIWA Director: A. H. Wymore, Kansas City.

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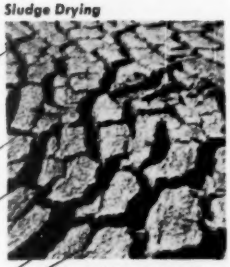

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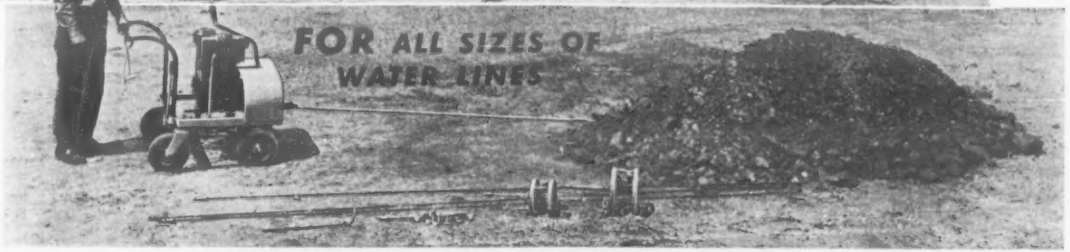

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